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Preliminary observations of flight activity of Trichoptera in the southern Cape, South Africa

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Abstract

In a study on flight activity it was observed that Trichoptera were attracted to a superactinic or UV light at a site along the lower Groot River near Nature's Valley in the Western Cape, South Africa. The frequency of insects passing selected fixed points in space was recorded photographically, after dusk, on 44 days between October 2011 and May 2012. All digital images of insects were identified to species, where possible, and abundance of species over selected time periods was determined. Water and air temperature, relative humidity, barometric pressure, wind direction and speed were continuously recorded during each recording event. Total dissolved solids (TDS), electrical conductivity, pH, the percentage of cloud cover, rain at the time of the survey, and rainfall prior to the survey, were all recorded. The dominant species during all surveys, *Athripsodes bergensis* Scott, revealed a modal peak of flight activity around 50 minutes after sunset which was strongly influenced by climatic variation. The presence of egg masses carried by females was observed from the middle of November through March, with the highest percentage of females with egg masses found from late November to early December. Other species of Trichoptera that were recorded flying appeared later after sunset than did *A. bergensis*. Statistically the most important factor influencing flight activity was the time in minutes after sunset. Clear, cloudless conditions resulted in reduced flight activity. Information on flight activity can be used to determine the optimum weather conditions and times for collecting Trichoptera when using light sources.

Key words: Leptoceridae, *Athripsodes bergensis*, photography technique, climatic and abiotic factors

Introduction

There have been suggestions that the evolution of swarming flight in Trichoptera was driven by situations when sudden increases in population density of a species resulted in increased tactile contact of individuals, leading to greater disturbance of settled adults, which led to increased *ad hoc* flight activity (Ivanov 1991). With a large number of adults continually in flight, the gradients of pheromone concentration, normally functioning to attract mating partners, would have been disrupted and would have rendered pheromone-induced mate attraction ineffective (Ivanov 1991). Flight activity in Trichoptera has been largely associated with mating and the formation of swarming behaviour is seen in species from many of the evolutionarily more derived families of caddisflies (Solem 1978, 1984; Ivanov 1991). Species in the integripalapian family Leptoceridae have revealed a number of behavioural flight pattern formations: from small scattered aggregations to dense swarms moving in zig-zag flight over the water surface, as small groups of insects flying in a disordered fashion above the water surface, or in vertical dance-like fashion in compact swarms (Ivanov 1991).

Observed flight activity of Trichoptera in East Africa was found by Corbet & Tjonneland (1955) to have a bimodal pattern around dusk and dawn. In a detailed study of Trichoptera along the shoreline of Lake Victoria near Jinja, Uganda, ten out of twelve species were found to have a flight activity peak around dusk, with most species displaying flying activity that decreased gradually throughout the night, while some species showed distinct short flight activity peaks after sunset and/or at dawn (Corbet & Tjonneland 1956). Three species had

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a peak of activity at dawn that, in a ten minute period, exceeded flight abundance for a similar time span at dusk. They concluded that flight in caddisflies was inhibited by light intensity above a certain level. Corbet (1965) suggested that flight activity in crepuscular species was confined within predictable low-light intensities in conjunction with favourable temperatures. In a study of flight periodicity in caddisflies, Harris (1971) found that most species attained their greatest peak of flight activity 40–50 minutes after light intensity, measured with a specially designed photometer that measured solar light intensity in microamperes, declined to four or fewer microamperes (= four foot-candles). Nimmo (1966) found that, besides light intensity, air temperature and wind speed accounted for 75% of the variation of counts of Trichoptera collected at set time intervals throughout a night. In contrast Waringer (1991) found that mean nightly wind speed seemed to have a minimal influence, but that there was a consistent increase in flight activity with increasing air temperature, with the highest numbers recorded during peaks of air temperature. Swarming flight activity at night, in two Northern European species of Phryganeidae, was noted to occur only when air temperatures were above 14°C (Solem 1984). A number of studies have shown that swarming behaviour is reduced and suppressed when temperatures fall below species-specific lower limits (see Petersson 1989 and references therein). The duration of seasonal flight activity has been intensively studied (Crichton 1960; Wagner *et al.* 2011). The duration of seasonal flight activity has been noted to vary considerably, ranging between three and 15 weeks for five species of Leptoceridae studied (Petersson 1989).

In a one-year study of aquatic insect species diversity in eleven rivers in the Tstitsikamma mountains, 48 species of Trichoptera were recorded and the leptocerid *Athripsodes bergensis* Scott, 1958, was found to be the dominant species at almost all river sites sampled. During spring, summer and autumn in each season, it attained a numerical abundance in excess of 94% of all Trichoptera species collected at light traps at the lower Groot River west (de Moor & Bellingan 2010; Bellingan 2011). Because it was so numerically abundant and almost exclusively dominant, it was an ideal species on which to conduct autecological and behavioural studies.

In this study we looked at the flight activity peak of *A. bergensis*, and assessed how measured climatic and abiotic factors influenced this. Flight activity was measured as the number of insects flying through a defined area in space over a selected time interval. This should not to be confused with population density, which would be a direct measure of the number of insects in the area surrounding the photographic recording rigs. It is, more appropriately, a measure of flight activity relating to the density and activity of swarming insects in the immediate vicinity of the recording apparatus.

Methods

Study site and photographic records

All data, including photographic images, were gathered between October 2011 and May 2012 at a single location on the Groot River (west) near Nature's Valley below the Tsitsikamma Mountains. The site and photographic methods used were described in detail by McIlleron & de Moor (2011). There have been considerable improvements made to the photographic rig, which is now very stable and capable of detecting insects over an array of intersecting beam pairs rather than a single pair. The modified rig, which uses improved electronics and infra-red beams in preference to laser beams, has eliminated ghosting, discussed previously (McIlleron & de Moor 2011). The beams have been arranged so as to provide nine points (Fig. 1) where pairs of beams intersect, with each beam of a pair being detected in a separate and independent detector. In the event of a simultaneous interruption of both beams of one or more of the pairs of beams, the flash units would be triggered so as to record a photograph of the insect that has interrupted a beam pair. The use of UV LED light sources, to attract insects to the photographic rig, has also been introduced to save energy and to simplify the electronic circuits. Photographic images were studied, and the insects that were recorded therein were identified to species level where possible. Every instance of a flash that resulted in a record of a single insect, or a number of insects in flight, was reduced to one record of flight activity, irrespective of the number of insects captured in the photograph. Only those images that showed at least one portion of an insect in sharp focus, in the region of one or more of the intersecting pairs of beams, were accepted for record purposes. The number of photographic records identified as *A. bergensis* were summed and recorded for each two-minute interval throughout the photographic session on each occasion. On some occasions the flight activity was recorded independently using two photographic rigs that had been set up at different positions within 100 m of each other at the study site. These were recorded under the date only, or under the same date but with an asterisk (*) added.

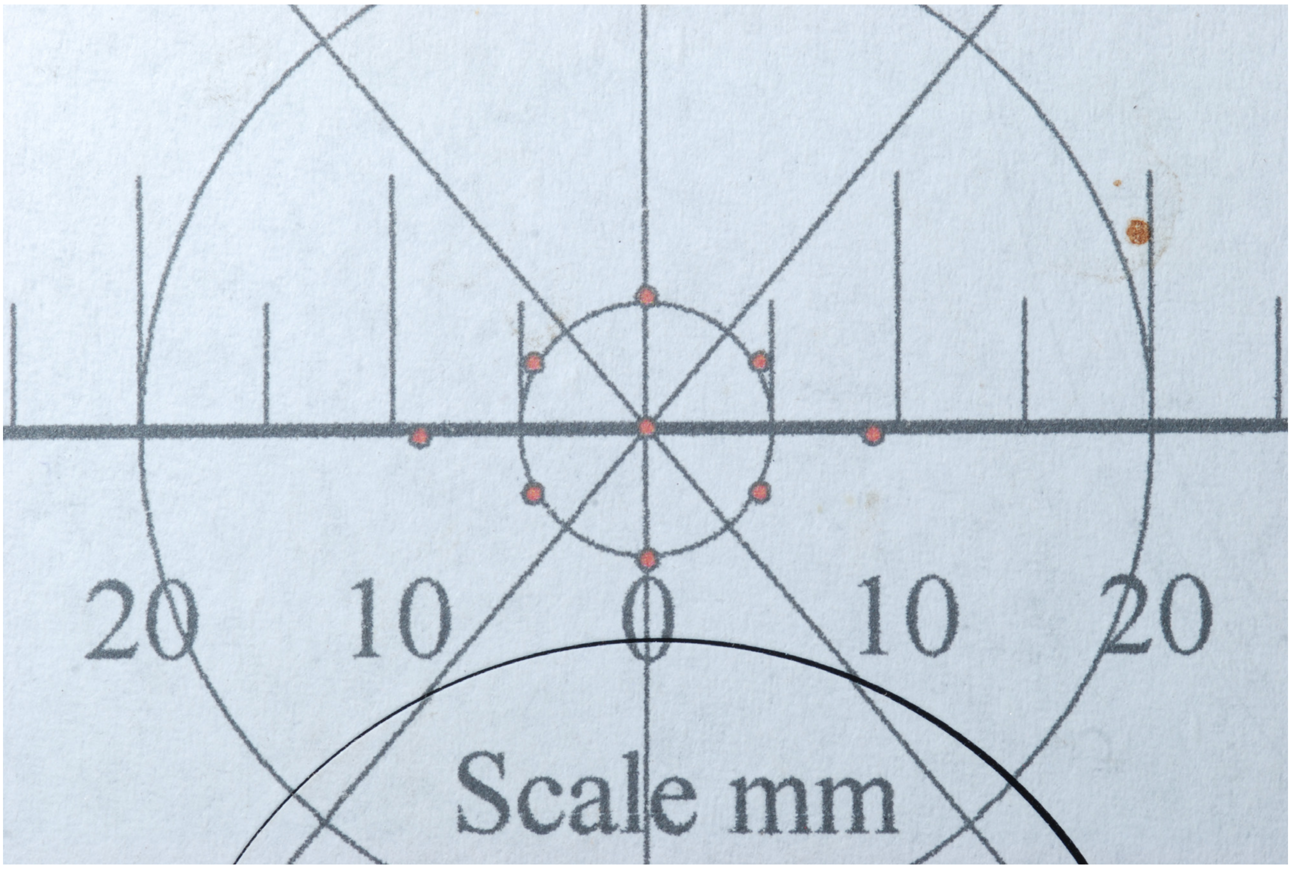

FIGURE 1. Photo of target sheet used for focussing and framing the image area showing nine points where infrared light beams intersect. Here the camera is positioned to record images just over 50 mm wide.

Flight activity is not an indication of population density at the time of recording. There may be large numbers of adults present that remain inactive under the particular prevailing conditions, or else swarming may occur at selected points, giving a random or locally aggregated distribution of adult swarms throughout the area. The correlation of the number of adults photographed against those collected in light traps set on several evenings, as well as the recorded differences in activity when two photographic recording stations were run simultaneously, reveals this (see Fig. 16).

Recording of climatic and abiotic data

Water and air temperature were recorded at two-hourly intervals throughout the study period by using Climastats, Thermocron i-button temperature data-loggers (–40 to 85°C ± 1°C accuracy at 0.5°C resolution). Data-loggers were placed in Ziploc® bags that were tied to a tree on the bank of the river (for recording air temperature) or in Ziploc bags placed in sealed plastic containers placed in a 50 mm-diameter, 300 mm long galvanised pipe closed at either end with stainless steel bolts and nuts (for recording water temperature). The pipe was attached to a boulder with a stainless steel cable and a rawlbolt (Fig. 2). The boulder and attached pipe were placed under water, downstream of a large embedded boulder (which formed a protected area) in a depression next to the river bank. Loggers were retrieved for data capture and replaced again at three-monthly intervals.

For each visit to the river after 18 November 2011, an Onset HOBOware® Weather Station was installed (Fig. 3) and was programmed to record at one minute intervals the following parameters: Air temperature; relative humidity at 0.1% resolution with an accuracy of 2.5%; barometric pressure (660–1070 ± 3mbar) with a resolution of 0.1mbar; light intensity, as photosynthetically-active radiation (PAR) at 400–700nm ±5%; average one-minute wind speed, and maximum three-second wind gust between 0–45ms^{-1} ± 4% with a resolution of 0.19ms^{-1}, as well as wind direction, recorded at approximately two metres above ground level;

and water temperature at depths between 100 and 300 mm below the water surface in a slow-flowing run in the river.

FIGURE 2. Boulder with stainless steel cable attached to galvanised pipe, with ends sealed by stainless steel nuts and bolts, used for storing Thermocron temperature recording i-buttons in plastic containers under water for extended time.

The water and air temperatures were recorded at a resolution of 0.03°C with an accuracy of 0.21°C and wind direction readings were interpreted in such a way as to record the wind as blowing either up or down the river valley only. The actual calculated time of sunset, rather than the GMT+2h standard time, was used for plotting all data.

Various other methods were used to measure additional parameters not covered by the Onset HOBOware® Weather Station, including the following: pH was measured with a Cyberscan pH 300®; electrical conductivity µScm^{-1} (EC) and total dissolved solids mgl^{-1} (TDS) using a WTW LF 95® conductivity meter, were recorded at various times during the survey. The status of weather was recorded as either overcast (O), clear (C) or changing (O/C) and the depth of water (either low or high) in a channel on the left hand bank was used as an assessment of the quantity of water flowing down the river during each night when photography was undertaken. Daily rainfall records, between July 2011 and May 2012, from two upstream weather stations—Crags (250masl), Bloukrans (252masl)—and one lower station at Nature's Valley (10masl), were also obtained.

Statistical analysis of data

Data on insect flight activity (counts per two minute interval) were recorded as time in minutes after sunset and all physicochemical data records were aligned to coincide with the activity counts recorded. Flight activity counts and all the physicochemical data were plotted against time for a visual oversight of possible factors influencing activity. After determining that the data collected fitted a Poisson distribution, a multiple regression (Generalized Linear Model) with categorical (dummy) and numerical predictor variables was fitted

(STATISTICA 2010). The flight activity records per two-minute interval were utilised as the dependent variable and related to the following two types of predictor variables: Numerical data (air and water temperature, relative humidity, barometric pressure, wind speed, and wind gust speed) and non-numerical data (weather as overcast or clear; wind direction, as up or down the river valley; and flow in the river, recorded as water depth, as either low or high). The data were run separately using either all parameters without the two selected weather codes or with the weather codes included. The Wald statistic was used to test the significance of the regression coefficient, and the level of the significance was set at $p \leq 0.05$.

FIGURE 3. Onset HOBOware® Weather Station set up to capture data at study site on Groot River.

Results and discussion

Electrical conductivity (EC) and Total Dissolved Solids (TDS) between October 2011 and March 2012 ranged from 92−109 μScm^{-1} and 82–97 mgl^{-1}, respectively, and pH ranged from 4.4–5.0. Rainfall of more than 60 mm (during the two week period prior to water chemistry being recorded) was noted between 22 March and 26 March. This may have contributed to an observed decrease in EC, TDS and pH levels during that period. The variation in water chemistry recorded does not appear to have had any influence on the flight activity patterns of *A. bergensis* observed and is not further considered in this study.

Figures 4–12 show a selection of data on flight activity and physicochemical parameters recorded on nine separate evenings. Wind speeds and gusts above 1 ms^{-1} (Figs 4–6) and frequent changes in wind direction (Figs 4, 7) resulted in lower flight activity. Counts were lower when the wind was blowing down the valley than when blowing up (Figs 7, 9). On most evenings a peak in flying activity, lasting for less than one hour, could be discerned (Figs 4–6, 8–9, 11) but there were exceptions where extended flight activity, lasting over 100 minutes, was recorded (Fig. 10). By the middle of April the flight activity had declined considerably (Fig. 12) and by May no more activity was recorded. The accumulated data for all observations revealed that peak flight activity of more than 15 counts per two-minute interval was attained between 28 and 76 minutes after sunset (Fig. 13). There was also a seasonal difference, with the onset of flight activity occurring earlier after sunset, but lasting for a shorter period of time in spring and autumn than in summer (Table 1). Air temperatures below 14.5°C and above 24.0°C, and water temperatures below 16.0°C, also seemed to coincide with reduced flight activity (Figs 14–15). For the range of temperatures recorded, there appeared to be no upper water temperature limiting flight activity in *A. bergensis*. The accumulated data for wind speed also indicate a decline in flight activity when wind speed exceeded 1ms^{-1}. It is, however, more likely that wind gusts caused the recorded declines in activity and this is further supported by the multiple regression analysis, discussed below.

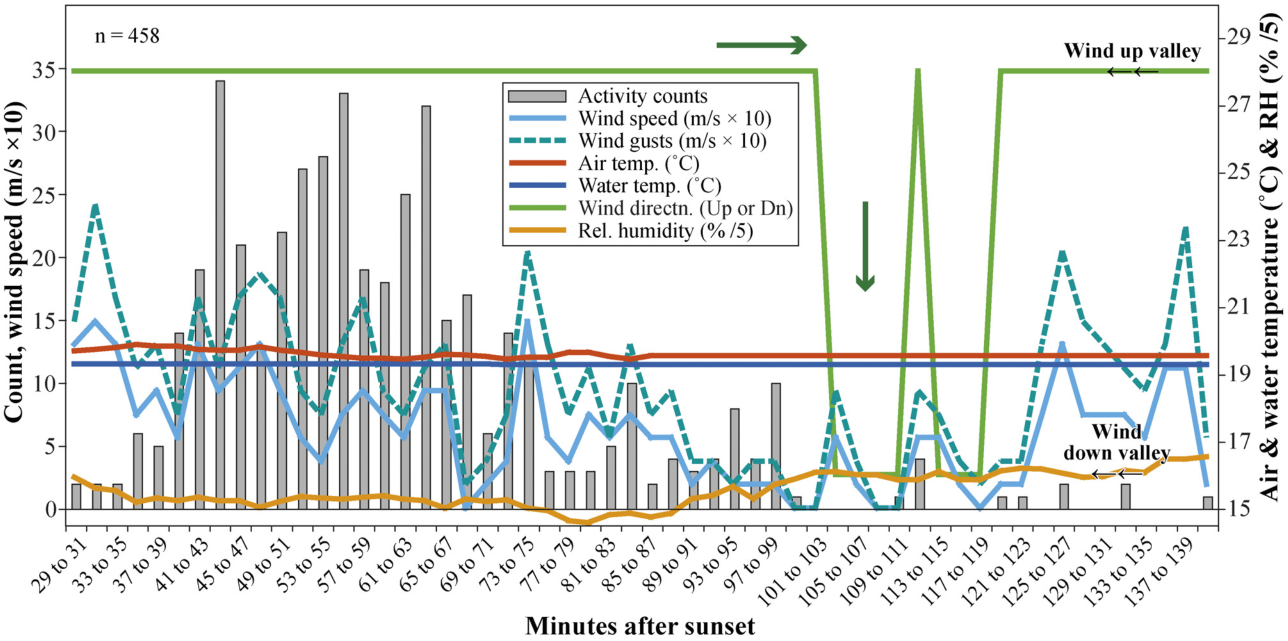

FIGURE 4. Flight activity of *Athripsodes bergensis* and selected environmental data recorded on 18 November 2011. Total flight activity records (counts) indicated by *n*. Arrows indicate change in wind direction from up to down valley and air and water temperature approaching equilibrium. Readings for wind speed and wind gusts should be divided by ten and relative humidity values should be multiplied by five.

TABLE 1. Commencement, peak time and duration of flight activity in minutes, observed for *Athripsodes bergensis* in the southern Cape South Africa

Time of year	Start of flight activity minutes after sunset	Period of peak flight activity (minutes)	Duration of peak activity (minutes)
October to early November	7	25–33	c. 10
Mid November to mid January	20	29–65	c. 30
March	19	35–50	c. 15

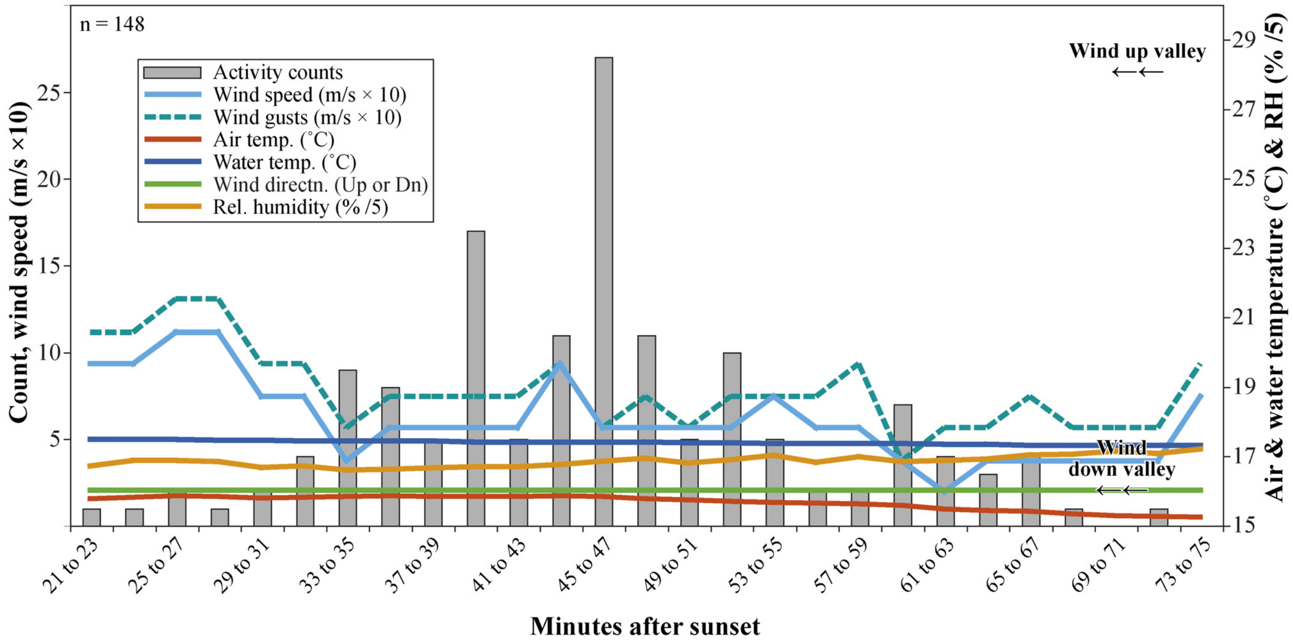

FIGURE 5. Flight activity of *Athripsodes bergensis* and selected environmental data recorded on 26 November 2011. Total flight activity records indicated by *n*. At wind speed below 1ms^{-1} highest activity was recorded. Readings for wind speed and wind gusts should be divided by ten and relative humidity values should be multiplied by five.

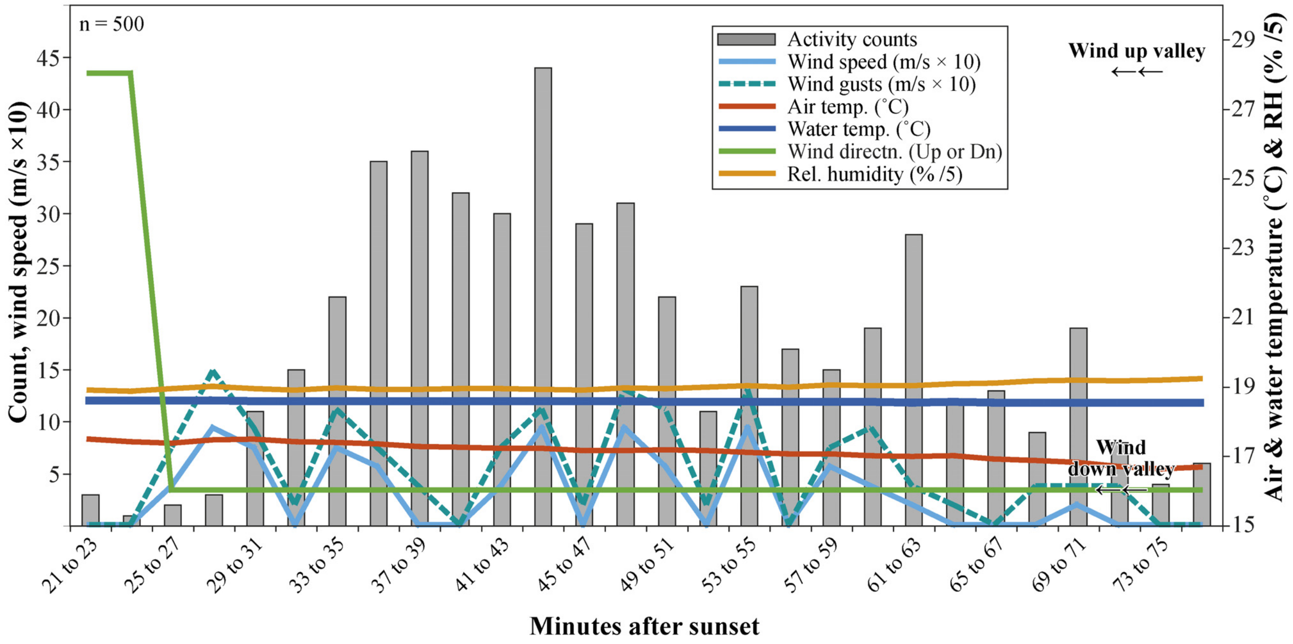

FIGURE 6. Flight activity of *Athripsodes bergensis* and selected environmental data recorded on 5 December 2011. Total flight activity records indicated by *n*. Change in wind direction and steady low wind speed, as well as high RH and water temp correspond with high activity. Readings for wind speed and wind gusts should be divided by ten and relative humidity values should be multiplied by five.

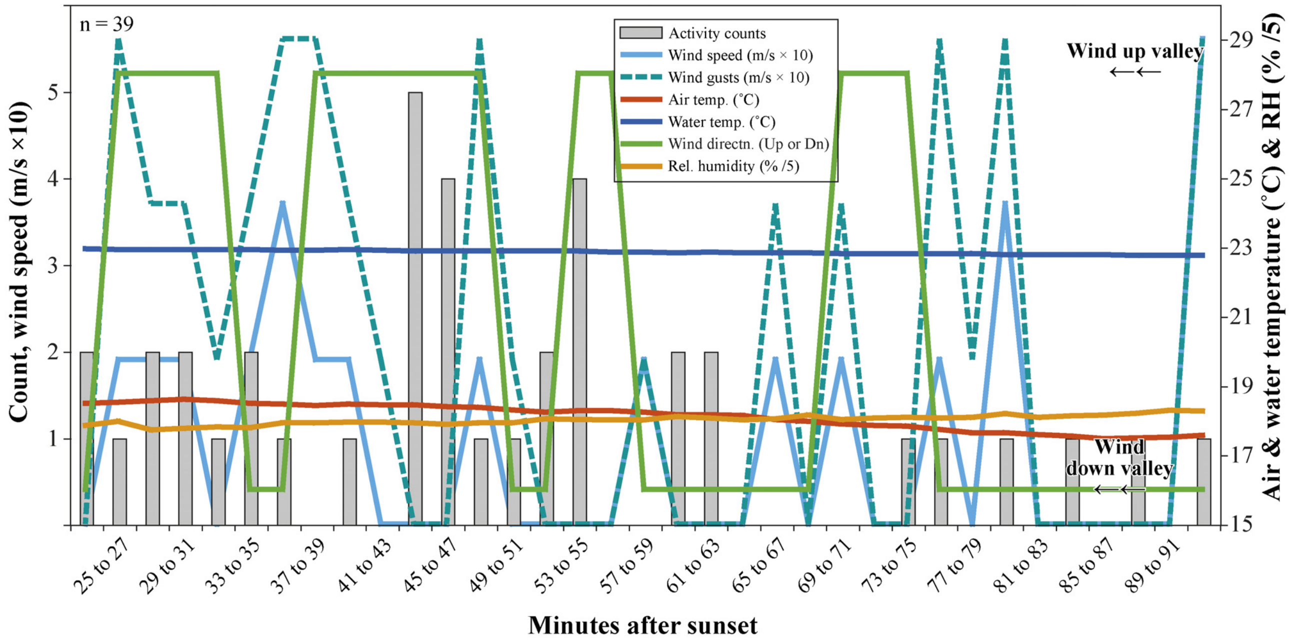

FIGURE 7. Flight activity of *Athripsodes bergensis* and selected environmental data recorded on 6 February 2012. Total flight activity records indicated by *n*. Note frequent changes in wind direction and low activity recorded. Readings for wind speed and wind gusts should be divided by ten and relative humidity values should be multiplied by five.

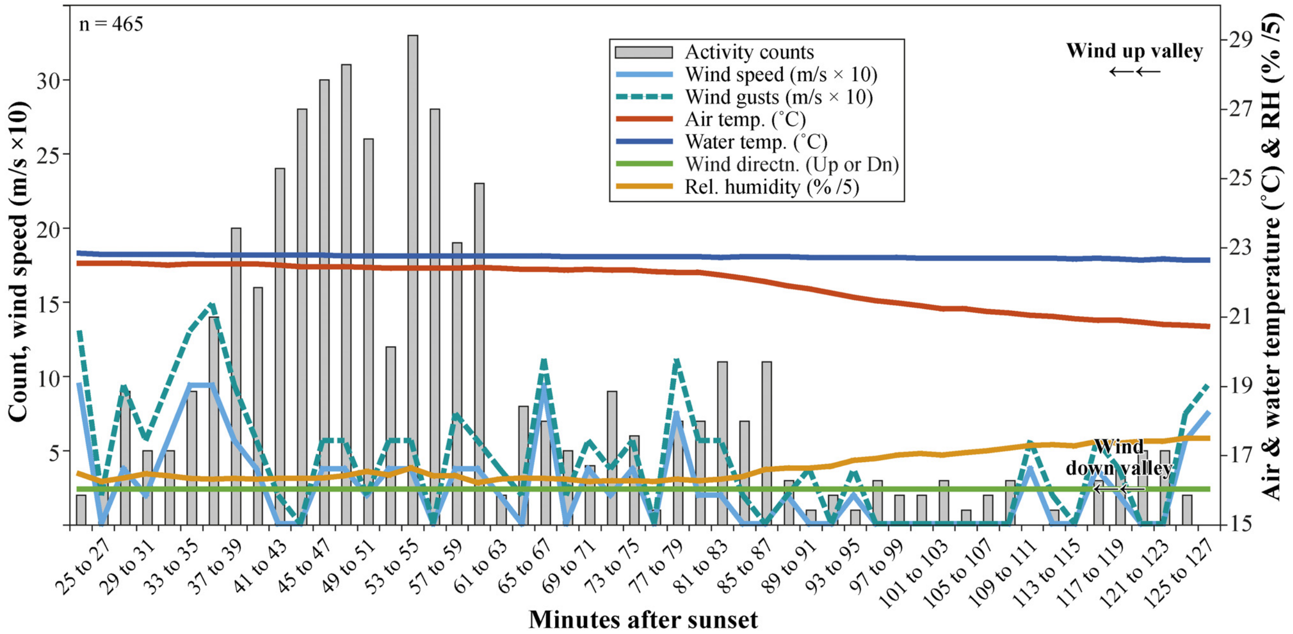

FIGURE 8. Flight activity of *Athripsodes bergensis* and selected environmental data recorded on 4 March 2012. Total flight activity records indicated by n. Peak activity from 39–65 minutes after sunset. Readings for wind speed and wind gusts should be divided by ten and relative humidity values should be multiplied by five.

Results of two categorical-predictor, multiple regression analyses are presented in tables 2 and 3. In the first analysis: time after sunset, air and water temperatures, and wind-gust speed were all highly significant ($p<0.000001$) and relative humidity, barometric pressure, and wind direction were all significant ($p<0.0002$) predictors of flight activity, while wind speed and water depth were not significant ($p>0.05$) (Table 2). In the second analysis, in which weather codes were introduced, the following factors were highly significant ($p<0.000001$) predictors of flight activity: time after sunset, barometric pressure, wind-gust speed, wind direction and weather codes. Relative humidity was a significant (p<0.02) predictor, while air and water temperatures, wind speed, and water depth were not significant (p>0.05) predictors in this second analysis (Table 3).

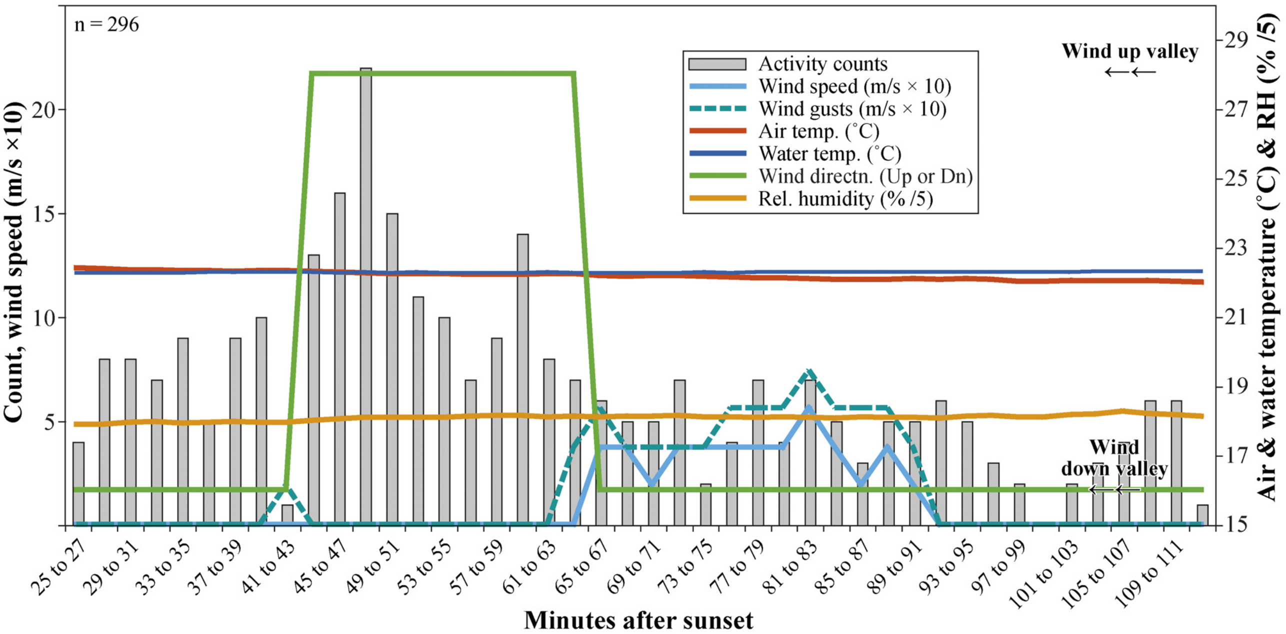

FIGURE 9. Flight activity of *Athripsodes bergensis* and selected environmental data recorded on 9 March 2012. Total flight activity records indicated by *n*. Change in wind direction, low speed and low gust speed as well as high air and water temperatures correspond with extended but low activity. Readings for wind speed and wind gusts should be divided by ten and relative humidity values should be multiplied by five.

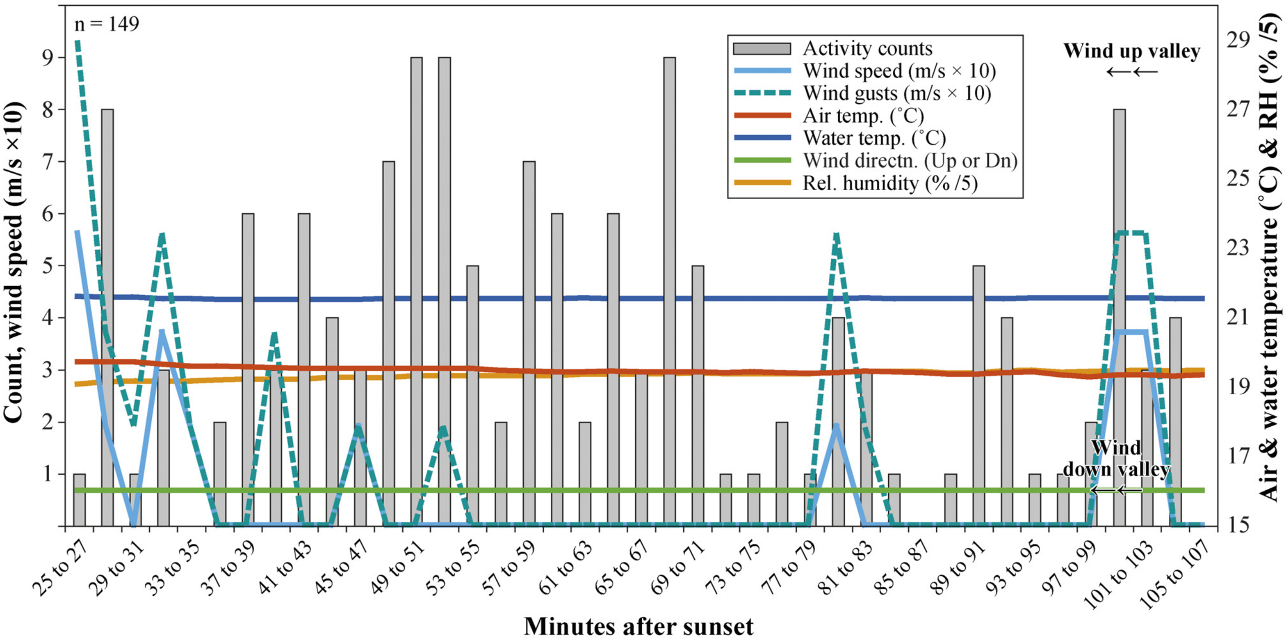

FIGURE 10. Flight activity of *Athripsodes bergensis* and selected environmental data recorded on 16 March 2012. Total flight activity records indicated by *n*. Note extended peak of flight activity for 78 minutes. Readings for wind speed and wind gusts should be divided by ten and relative humidity values should be multiplied by five.

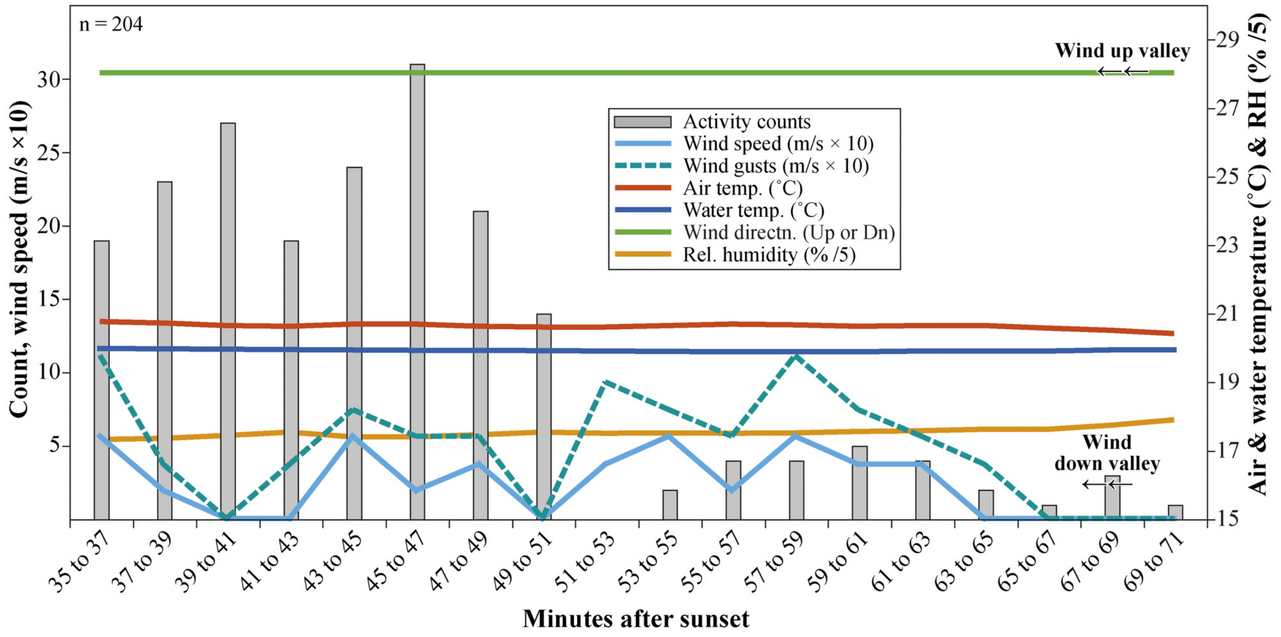

FIGURE 11. Flight activity of *Athripsodes bergensis* and selected environmental data recorded on 22 March 2012. Total flight activity records indicated by *n*. Note sharp peak of flight activity lasting 16 minutes. Readings for wind speed and wind gusts should be divided by ten and relative humidity values should be multiplied by five.

TABLE 2. Summary data and test of all effects of a multiple regression analysis of selected categorical predictor parameters of flight activity records of *Athripsodes bergensis*. ***Highly significant p<0.00001, ** Significant p<0.002, * Significant p<0.05

Effect	Level of Effect	Col.	Estimate	Standard Error	Lower CL 95.0%	Upper CL 95.0%	Wald Stat.	p
Intercept		1	18.08786	4.070315	10.11019	26.06554	19.7478	0.000009 ***
Time Mins after sunset		2	-0.01273	0.000610	-0.01392	-0.01153	435.9260	0.000000 ***
Air Temp		3	0.13545	0.013524	0.10894	0.16196	100.3101	0.000000 ***
Water Temp		4	-0.11326	0.013752	-0.14021	-0.08630	67.8266	0.000000 ***
Barometric Pressure		5	-0.01429	0.003885	-0.02190	-0.00667	13.5184	0.000236 **
Wind Speed		6	-0.00946	0.013252	-0.03544	0.01651	0.5100	0.475155 NS
Wind gust Speed		7	-0.06182	0.009113	-0.07968	-0.04395	46.0150	0.000000***
Relative Humidity		8	-0.06555	0.013650	-0.09231	-0.03880	23.0655	0.000002***
Wind Direction Code	Down	9	-0.06190	0.019186	-0.09950	-0.02429	10.4078	0.001255**
Water depth Code	low	10	0.05565	0.029275	-0.00172	0.11303	3.6140	0.057295 NS

Time after sunset was by far the best predictor of flight activity and remained highly significant in both analyses (Tables 2, 3). Air and water temperatures were both good predictor variables for the first analysis but were not significant predictor variables (p>0.05) for the second. The weather code, introduced for the second multiple regression analysis, was a very good predictor. Overcast cloudy conditions would indicate higher relative humidity and possible imminent rainfall, as well as serve to maintain higher air temperatures. It was, however, the clear sky weather code (C) that was a highly significant (p<0.000001) negative indicator of flight activity, indicating that clear skies are good indicators of reduced flight activity. The influence of moonlight was considered not to have had any significant impact on caddisfly flight activity because the steep-sided and forested gorge would only allow the moon to illuminate the observation site when the moon was between 40 and 130 degrees above the horizon. This would have occurred between four and 12 days before full moon and would exclude the influence of the full moon phase (plus three days before and three days after this event) when the moon would be of sufficiently bright enough intensity to influence flight activity at the observation site. Whenever these conditions occurred it was well after the peak of flight activity observed. The weather code as a predictor serves to integrate (or reflect a combination of) the other predictors discussed. It is apparent that when the wind blows up the river, gusts are more frequent than when it blows down the river and when this happens, as predicted, there is slightly lower flight activity, although this was not significant. This observation however serves to emphasise how important gusts are in inhibiting instantaneous flight activity. Barometric pressure also proved to be a significant predictor and this is understandable: As it rises it predicts drier conditions and a barometric pressure above 1024 mbar results in a distinct decline in flight activity. Lower barometric pressure indicates higher relative humidity and is notable when cloudy conditions prevail or when conditions for rainfall are suitable. The PAR light levels fell to zero soon after sunset and the light intensity levels that we recorded were too insensitive to be useful as a predictor variable.

The total number of photographic flight activity records gathered on each evening, together with the recorded percentage of individuals carrying eggs masses (based on the total number of *A. bergensis* photographed that evening), showed a distinct bi-modal period of egg-laying activity. The first period was between late November 2011 to early January 2012, and a second period from the middle to the end of March 2012, when a much-reduced percentage of females carried egg masses (Figs 16–17). Outside the observed peak periods, a low number of females were still observed carrying egg masses between mid-January through to mid-March. A continuous recruitment of eggs and larvae was thus observed from November through March the following year. On a number of occasions, two independently-recorded photographic sessions on one evening revealed that there may be considerable variation of flight activity along a section of river (Fig. 16).

TABLE 3. Summary data and test of all effects of a multiple regression analysis of selected categorical predictor parameters of flight activity records of *Athripsodes bergensis*. With additional weather code parameters added. ***Highly significant p<0.00001, ** Significant p<0.002, * Significant p<0.05

Effect	Level of Effect	Col.	Estimate	Standard Error	Lower CL 95.0%	Upper CL 95.0%	Wald Stat.	p
Intercept		1	30.40298	4.597347	21.39234	39.41361	43.7338	0.000000 ***
Time Mins after sunset		2	-0.01537	0.000641	-0.01663	-0.01412	575.5331	0.000000 ***
Air Temp		3	-0.02314	0.017823	-0.05807	0.01179	1.6856	0.194185 NS
Water Temp		4	0.01233	0.017246	-0.02147	0.04613	0.5109	0.474747 NS
Barometric Pressure		5	-0.02627	0.004371	-0.03484	-0.01770	36.1119	0.000000 ***
Wind Speed		6	-0.00247	0.013444	-0.02882	0.02388	0.0339	0.853998 NS
Wind gust Speed		7	-0.05663	0.009322	-0.07490	-0.03836	36.9014	0.000000 ***
Relative Humidity		8	-0.03462	0.014722	-0.06347	-0.00576	5.5288	0.018706 *
Wind Direction Code	Down	9	-0.11805	0.021373	-0.15995	-0.07616	30.5092	0.000000 ***
Water depth Code	low	10	0.04911	0.031638	-0.01290	0.11112	2.4092	0.120625 NS
Weather Code	O	11	0.01393	0.026061	-0.03715	0.06501	0.2858	0.592950 NS
Weather Code	C	12	-0.54323	0.035949	-0.61369	-0.47278	228.3518	0.000000 ***

Conclusions

The peak flight activity, occurring within one hour (mode of around 50 minutes) after sunset, would indicate a synchronisation of the reproductive activity state in the life cycle in *A. bergensis*. In tropical low–latitude regions the peak flight period is more synchronised in the short crepuscular period than it would be in the temperate regions, where the twilight conditions last much longer (Corbet & Tjonneland 1956). In the present study it was noted that the daily duration of flight activity was shorter in October to early November (Spring) and in March (Autumn) than it was in the late November to mid-January period (Summer). Twilight lasts much longer in summer: Thus these observations support the prediction made by Corbet & Tjonneland (1956). Flight activity also commenced sooner after sunset in spring than in summer, although it was not much earlier than that observed for mid-summer than in March. This suggests that air temperatures, which are warmer in late summer and autumn than in spring, would play an important secondary role in influencing the commencement of flight activity. Reduction in flight activity was also clearly influenced more by the colder air temperatures in this temperate region (latitude 33°57' 58"S) than in the low-latitude tropical regions.

The seasonal duration of flight activity in *A. bergensis* occurred from late Spring to early Autumn, nearly six months. There was a distinct seasonal pattern of Summer flight activity related to reproductive activity, as revealed by the peak in abundance of egg masses in females, between late November, through December, to mid-January.

This study revealed a number of important predictors of flight activity of *A. bergensis,* with time after sunset and overcast conditions being the most important. Other important factors are as follows: That very little flight activity occurs below air temperatures of 14.5°C and water temperatures below 16.0°C; that air temperatures above 24°C appear to have some inhibitory influence on flight activity in this region although low relative humidity and wind could also play a role; that gusty wind conditions are also not suitable for flight, and that activity is reduced at wind speeds above 1ms^{-1}. It is important to note that records such as those made by Waringer (1991), using mean nightly values for factors such as wind speed and rainfall, would mask the impacts of certain short-lived events that were noted in the present study. For example, the observation that individual gusts of wind or squalls of rain can stop flight activity for short periods of time within a night.

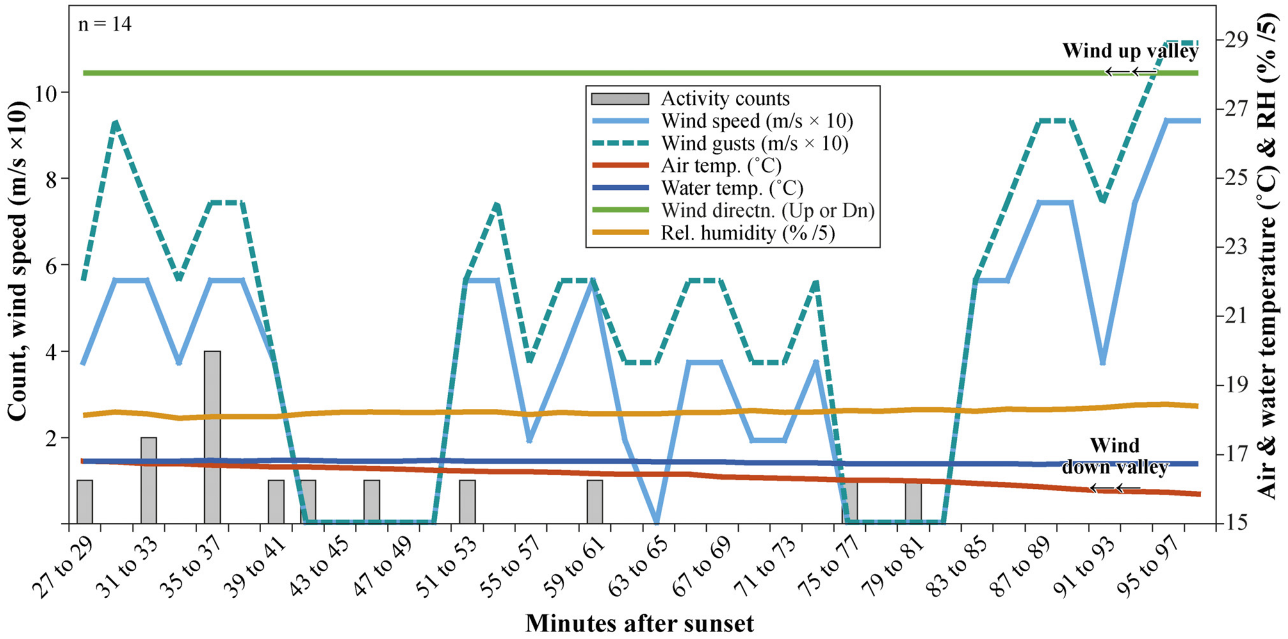

FIGURE 12. Flight activity of *Athripsodes bergensis* and selected environmental data recorded on 18 April 2012. Total flight activity records indicated by *n*. Note reduced activity towards end of the flying season. Readings for wind speed and wind gusts should be divided by ten and relative humidity values should be multiplied by five.

The tall Afromontane forest and steep gorges surrounding the Groot River valley play an important role in buffering the effects of strong winds. This allows longer periods of flight activity, thus enhancing reproductive success during the swarming behaviour of *A. bergensis*. Such activity would be much reduced in a river with more open terrain. The maintenance of a large, numerically-dominant population of this species at this site recorded over several years (2008–2012) supports this hypothesis.

The observations on factors influencing flight activity reported here could be developed for other species and could be used for refining the selection of suitable conditions and times for setting light traps and optimising the chances of collecting selected species.

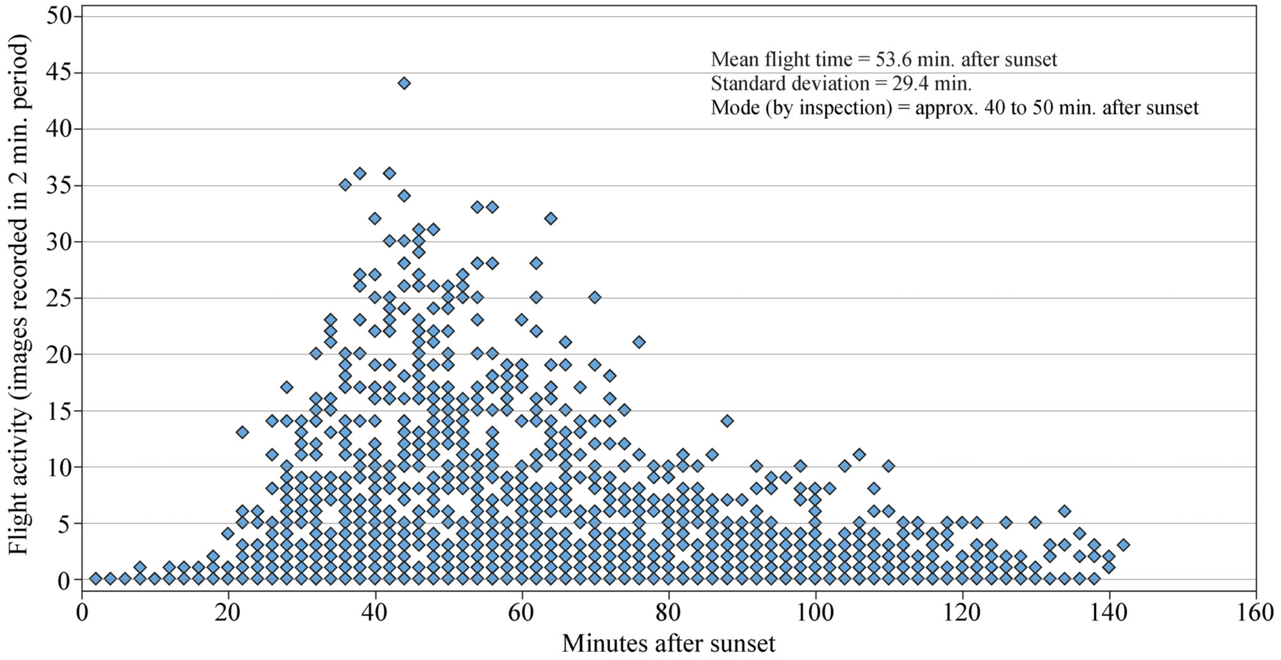

FIGURE 13. Flight activity counts of *Athripsodes bergensis* recorded at two-minute intervals plotted against time recorded, in minutes after sunset, between October 2011 and May 2012. Note that each square can represent a single or a multiple number of frequency counts and may not indicate the number of times any particular frequency count was recorded. Sum of all counts = 7867.

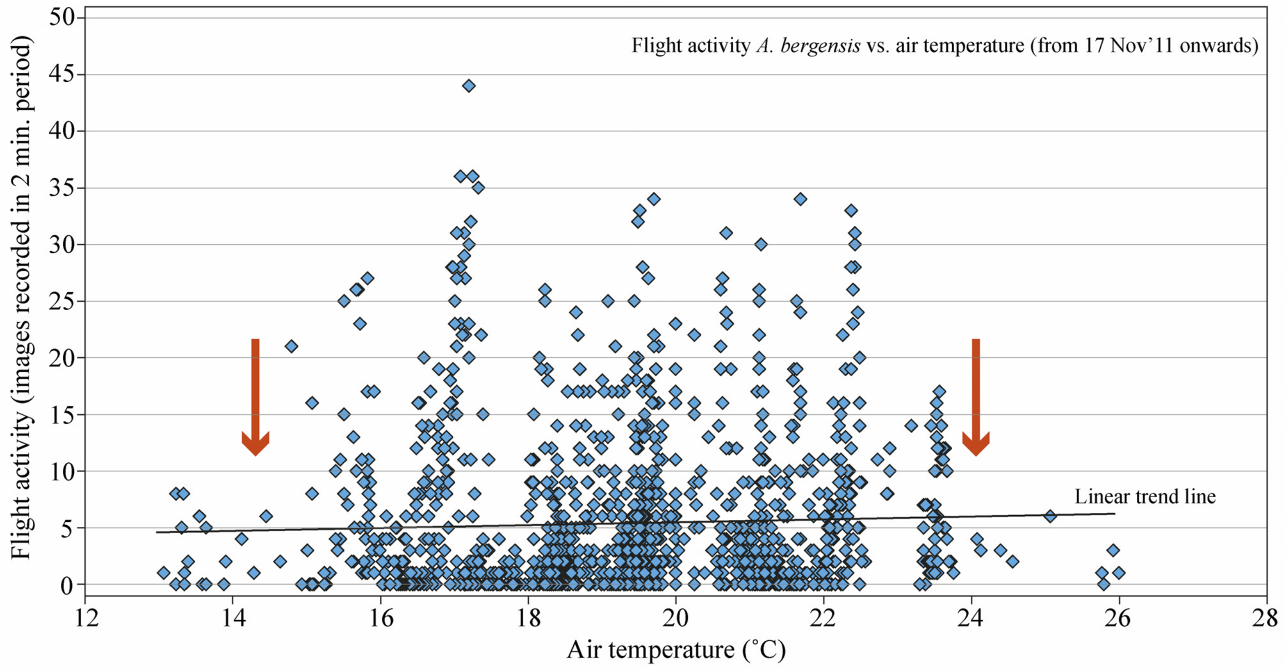

FIGURE 14. Frequency of flight activity counts of *Athripsodes bergensis* recorded at two-minute intervals plotted against air temperature between October 2011 and May 2012. Arrows indicate temperatures below and above which there is reduced activity.

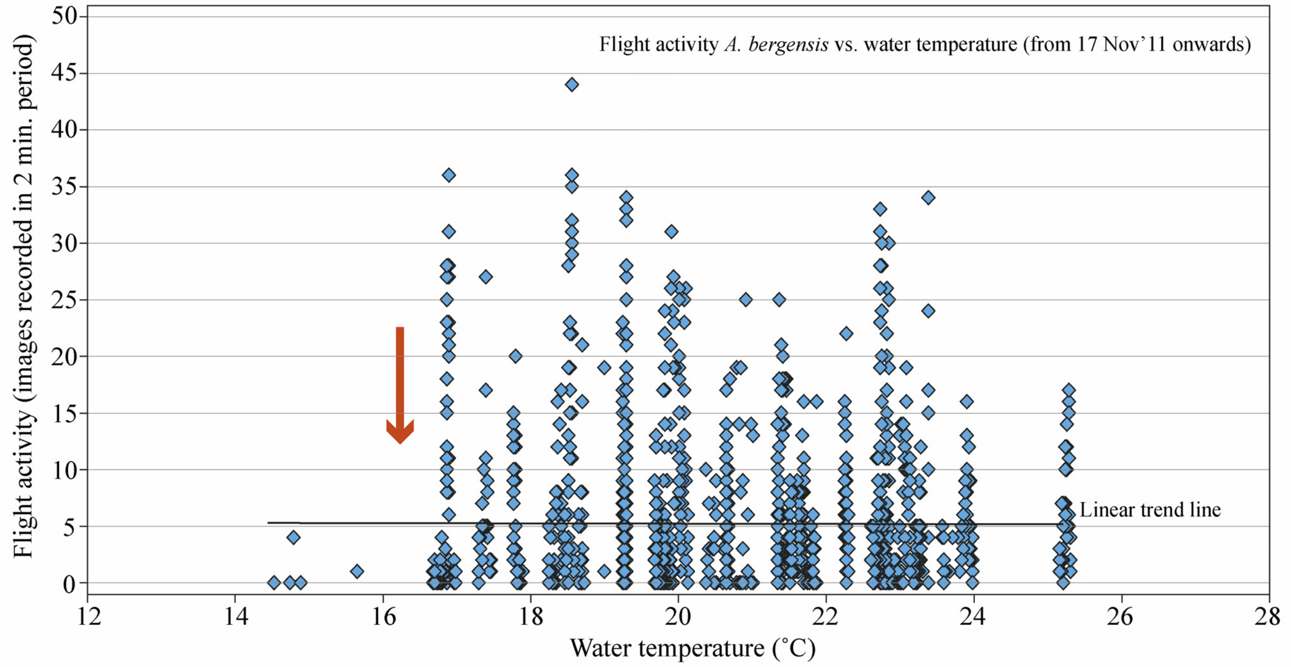

FIGURE 15. Frequency of flight activity counts of *Athripsodes bergensis* recorded at two-minute intervals plotted against water temperature between October 2011 and May 2012. Arrow indicates temperature below which there is reduced activity.

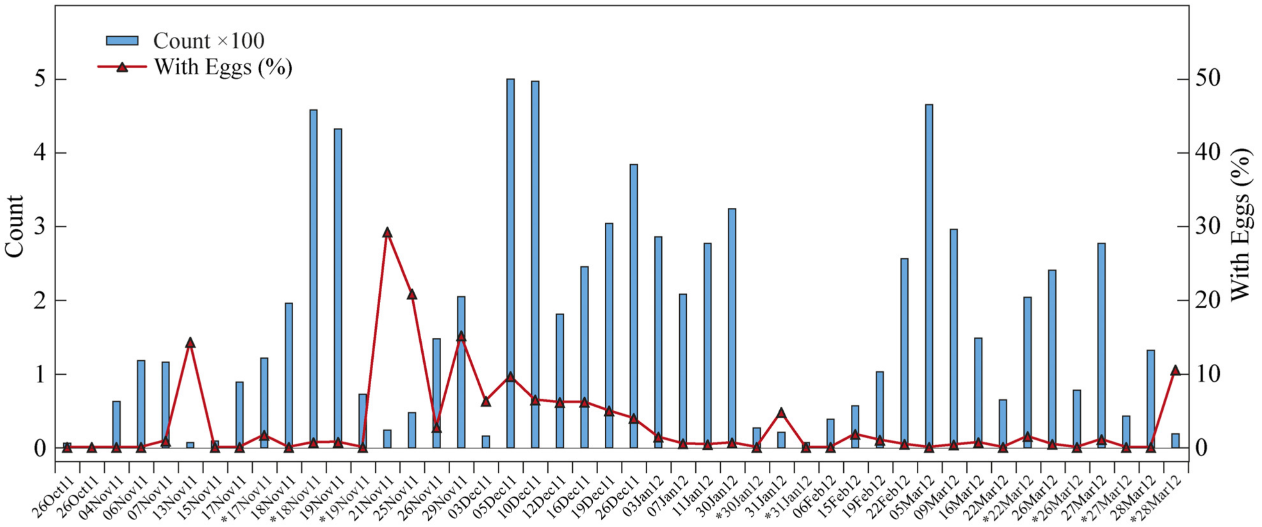

FIGURE 16. Overview of *Athripsodes bergensis* flight activity counts between 26 October 2011 and 28 March 2012 and the percentage of recorded females carrying extruded egg masses. Note that dates for which a second separate recording was made are each indicated by an asterisk (*). (The count figures should be multiplied by 100)

FIGURE 17. A female *Athripsodes bergensis* with extruded egg mass ready for being oviposited.

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