Lampyrid 2012. **3**:1-16

Lunar effects on the bioluminescent activity of the glow-worm *Lampyris noctiluca* and its larvae

Pamela Gunn & Brian Gunn

Lakeside, Dereham Road, Whinburgh, Dereham, Norfolk NR19 1QU.
**Email: pamelagunn@waitrose.com*

ABSTRACT Observations made during the late summer of 2011 on the glow-worm *Lampyris noctiluca* and its larvae have revealed that the larval bioluminescent activity appears to be strongly influenced by the phase of the moon. By contrast the glowing activity of the adult females seem to be uninfluenced by the lunar cycle.

Keywords: lunar phase, bioluminescence, glow-worm, *Lampyris noctiluca*, Norfolk

INTRODUCTION

At a site in Norfolk bioluminescent activity of glow-worms (*Lampyris noctiluca*) had been previously monitored in 2010 by counting numbers of glowing females and larvae to support the Norfolk Biodiversity Information Service's glow-worm survey, although the figures obtained were much more detailed than the survey required. Counting was stopped on 23rd July 2010 when there were only 3 females seen as it appeared that this was probably the end of the glowing season. During the recording in 2010 we had observed larvae, but these were included in the 'glowing count' and not treated separately. In 2011 we were motivated to build on this data by continuing the monitoring until no glowing insects were found i.e. until we had a count of zero for at least a week. We had no pre-conceived ideas of how long the 'glowing' season would last, and very little glow-worm knowledge other than the females glowed during June and July to attract their flying non-glowing mates. We knew that later in the glowing season their larvae could be identified by their 'flashing' i.e. by their not emitting light continuously. The object of our monitoring was to record comprehensively and separately the numbers of females and larvae for the entire 2011 glowing season and then to submit these figures to the Norfolk Wildlife Trust and the Norfolk Biodiversity Information Service. On analysis of these results an unexpected link was revealed between larval bioluminescent activity and the lunar cycle.

It had been thought by the observers that the lunar cycle's effect on the larvae and the attendant low counts during the full moon were probably well documented,

but a subsequent literature search however revealed no earlier reports of this lunar cycle link. This prompted a broader literature search for similar lunar effects on various organisms to place into context the observed lunar influence on the glow-worm larvae reported here.

Although the effect of the lunar cycle in humans and animals has not received the same interest as seasonal and circadian rhythms, some studies have been documented and are reviewed (Zimecki 2006) showing effects as diverse as the menstruation period of humans, melatonin levels and immune responses of rodents and biochemistry of honeybees. A report in 1980 on lunar and menstrual phase locking (Cutler) shows that correlation was found between ovulation and the lunar cycle. Behavioral effects have been linked with the lunar cycle, and hospital reports of animal bites during the full moon were studied (Bhattacharjee et al. 2000) and it was found that there was a significant increase during this period. Studies on human aggression and crime and the lunar cycle (Lieber 1978; Thakur & Sharma 1984) also show positive lunar phase correlation. If the lunar cycle affects the higher animals like humans, who live in conditions far removed from 'nature' i.e. in houses and with artificial lighting, then it is not surprising that the lunar cycle has some effect on the activity of other organisms including the nocturnal predatory larvae of the glow-worm.

The blood-feeding or biting behaviour on humans of sandflies, *Lutzomyia whitmani* and *Lutzomyia intermedia,* had a positive correlation with the full moon (Souza et al. 2005), as reported with various species of *Culicoides* biting midges (Lillie et al. 1988). A circabiseptan (14 day rhythm) of the predatory activity of mites *Typhlodromus pyri* was found to be statistically significant, with a depression in activity around the full moon (Mikulecky & Zemek 1992).

The effect of moonlight and lunar phase has been studied with respect to the spawning of marine organisms such as coral *Acopora humilis* and the snapper *Pagrus auratus* and positive correlations were recorded (Boch et al. 2011; Wakefield 2010). Rabbit fishes, *Siganus* known to spawn synchronously with a species-specific lunar phase, have been studied for lunar cycle linked physiological body changes, such as hormonal changes in the testis (Rahman et al. 2003) and plasma melatonin rhythms (Rahman et al 2004; Takemura et al. 2004). In worker honeybees, variations in haemolymph carbohydrates were found with concentrations peaking at full and new moon (Mohssine et al. 1990), and a follow-up study (Mikulecky & Bounias 1997) examined the haemolymph lipid concentrations, again finding circadispetan rhythms. In both studies a circaseptan (7 day) rhythm was also noted.

Studies on the marine midge chironomid *Clunio*, which has a semi-lunar and lunar reproductive rhythm, have examined aspects such as zeitgeber conditions (Neumann 1989) and genetic control of lunar emergence times (Kaiser et al. 2011). A study on how the midge perceives moonlight to enable photic synchronization of the lunar clock revealed that a change of shielding pigment transparency in the larval ocelli was lunar-rhythmic (Fleissner et al. 2008).

Myrmeleon obscurus larvae as measured by pit volumes has been shown to possess a monthly lunar rhythm, with a peak at full moon (Youthed & Moran 1969). Moonlight was found to be a 'zeitgeber' or phase-setting factor for these rhythms, and the article suggests that there is no functional significance for these rhythms, but occur from a chance phase setting influenced by moonlight. A subset of the pacemaker neurons of the fruit fly *Drosophila melanogaster* has been shown to respond to nocturnal dim light, and result in an increase of fly activity, whereas an inverse effect occurs with the clock proteins, PERIOD and TIMELESS (Bachleitner et al. 2007).

The dung beetle, *Scarabaeus zampesianus* uses the polarization pattern of the moonlit sky to orientate, at present the only species known to do so. In studies carried out using the nocturnal straight-line dung-rolling activity to determine the relative importance of the moon and the nocturnal polarized light pattern, it was demonstrated that the moon itself was not the primary cue for orientation, but the polarized light pattern of the moon was (Dacke et al. 2004). The celestial polarization pattern declines as the moon wanes, and the moon is not always visible, so in a later study (Dacke et al. 2011) the ability of the dung beetle to orient in the various celestial polarization patterns was investigated. It was demonstrated that celestial orientation was as accurate during the crescent moon as it was during a full moon.

The above studies indicate that the moon has a strong influence on the behaviour and physiology of many species and the reported lunar effect on the glow-worm larval bioluminescence in this paper is not unusual, although it is a negative or inverse correlation in contrast to most of the observations found which are either positive or circadiseptan.

MATERIALS AND METHODS

The location for the glow-worm monitoring was on a walk on private property with a large man-made lake. This walk consists mainly of a 300 metre linear path along a dyke between the lake and a ditch adjacent to a railway embankment. The lakeside of the walk has water vegetation of common reed *(Phragmites australis)*, sedge *(Carex sp.)* and great reed-mace *(Typha latifolia)*, and various grasses and wild flowers. On the railway embankment side of the path is a roughly maintained hedge predominately of bramble *(Rubus fruticosus)*, dog wood *(Cornus sanguinea)*, blackthorn *(Prunus spinosa)* and hawthorn *(Crataegus monogyna)* fronted by wild flowers and grasses. The dyke path itself is mown occasionally, but on either side the vegetation is largely undisturbed. Observations were concentrated on the lake shore area on the outward part of the walk and on the railway embankment side on the return.

We conducted the walks where possible on alternate nights at around 10:45 pm BST, this being the earliest to view the glowing females around the time of the summer equinox. We followed a consistent path noting temperature, time,

visibility and weather conditions e.g. wind and wet. Moonlight was also monitored as part of the 'visibility' record and whether or not the moon was behind clouds. These conditions were recorded so that where counts were unexpectedly high or low we could look back at them for a possible explanation.

The two of us conducting the monitoring walked separately, one walking a few metres behind the other. During the walk which took about 1 hour, no torch was used although one was taken for safety purposes (once used to fend off an inquisitive deer). On and after 16th October to save time the monitoring walks were curtailed to the initial 50 metres of the path as it had been observed that this produced around 90% of all larvae recorded on a full walk.

At first the counts were of glowing females i.e. steady bright bioluminescence. In all cases both recorders verified the existence of the glowing female in order for it to be counted. The larvae were first identified later in the season by their very much dimmer light in comparison with the females and also by their glowing for a short burst (anything from a few seconds to up to two minutes) and then 'turning off' the glow. During this report this may be referred to as 'flashing'. The 'off' period varied but was often minutes rather than seconds. It is extremely difficult to count accurately the larvae with their sporadic 'flashes'. However, where possible both observers verified the glowing larvae, if necessary by waiting until they turned 'on' or 'off' again. During the period when both larvae and females were present, one walker recorded the larvae and the other the females. On occasions there were so many larvae glowing it was almost impossible to count accurately, but the best attempt was made between the two observers to be as consistent and accurate as possible. During times of bright moonlight the observers used their own shadows to enhance visibility, and to exclude false counts such as reflections of moonlight in raindrops. Because the two observers were the same throughout the monitoring period inaccuracies due to different personnel were eliminated.

The 'flashing' larvae were assumed to be the larvae of the glow-worm *Lampyris noctiluca* because of their characteristic bioluminescence and their location being similar to that of the glowing females. The monitoring was continued after a count of zero on 4th November to ensure that the end of the season was accurately recorded. Two consecutive zero recordings on 8th and 24th November confirmed the end of our glowing season.

RESULTS AND DISCUSSIONS

The observation of one steady glow on 28th August was unusual as it was well outside the normal distribution of the glow-worms recorded, the previous female being observed 17 days earlier.

In Table 1 the total glowing season can be seen to be from 13th June with the first glowing females to the 1st November with the last single glowing larvae. It was noted that the larvae first appeared on 10th July which was 10 days later

	Females	Number	Larvae	Number
First observed	13th June 2011	7	10th July 2011	2
Peak	8th July 2011	31	29th September 2011	130
Last observed	28th August 2011 *	1	1st November 2011	1

* The observation of one steady glow on 28th August was unusual as it was well outside the normal distribution of the glow-worms recorded, the previous female being observed 17 days earlier.

Table 1 Glowing season (2011) for females and larvae.

than recorded in 2010. These results had achieved our primary objective for the monitoring although other interesting observations were deduced from analysis of the recorded data (Table 2).

Female distribution curve

The first record of a glowing female was on 13th June with a count of 7, and at the season's peak 31 were recorded on 8th July, with the last one observed on 28th August (Fig. 1). The distribution curve appears to be fairly normal with the exception of the appearance of a single female on 28th August. One 'dip' in the curve was a low reading on 29th June with 12 females. The continuous bright glow of the females makes them much easier to see and so their count is much more reliable than the larval count, as is illustrated in the comparatively steady nature of the curve. The dip in the count on 29th June is unexplained.

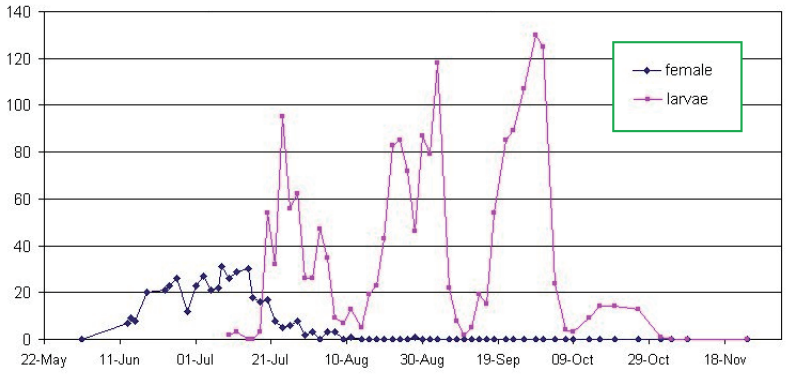

Figure 1 Larval and adult female counts for 2011.

Date (2011)	Start Time GMT	Larval count	Lunar Phase (100=Full)	Lunar Apparent Magnitude	Lunar Azimuth	Lunar Elevation
10-Jul	21:50	2	73.69	-11.84	192	14
12-Jul	21:35	3	89.83	-12.14	162	11
15-Jul	21:45	0	100.00	-12.20	127	4
16-Jul	22:35	**0***	98.93	-12.13	125	8
18-Jul	22:00	3	90.25	-11.87	96	-1
20-Jul	22:00	54	74.31	-11.49	74	-5
22-Jul	22:15	32	53.98	-10.98	55	-8
24-Jul	22:00	**95****	32.93	-10.26	30	-12
26-Jul	21:20	56	14.96	-9.18	11	-14
28-Jul	22:05	62	3.31	-7.06	342	-15
30-Jul	21:48	26	0.10	-1.75	312	-12
01-Aug	21:30	26	5.88	-7.57	281	-4
03-Aug	23:30	47	19.63	-9.73	278	-16
05-Aug	21:15	35	38.86	-10.82	225	8
07-Aug	21:00	9	60.10	-11.51	196	12
09-Aug	21:25	7	79.52	-11.92	175	13
11-Aug	21:45	13	93.61	-12.13	154	15
14-Aug	21:15	**5***	99.57	-12.13	118	13
16-Aug	21:25	19	92.39	-11.94	92	5
18-Aug	21:25	23	77.56	-11.64	70	0
20-Aug	22:05	43	57.75	-11.20	57	0
22-Aug	21:15	83	36.55	-10.59	25	-11
24-Aug	21:45	85	17.77	-9.61	8	-16
26-Aug	21:20	72	4.81	-7.85	336	-19
28-Aug	20:55	46	0.01	-3.23	296	-12
30-Aug	21:20	87	4.22	-7.16	279	-14
01-Sep	21:07	79	16.70	-9.50	249	-5
03-Sep	20:45	**118****	35.19	-10.69	219	5
06-Sep	21:15	22	66.74	-11.64	189	15
08-Sep	21:55	8	84.79	-11.96	174	21
10-Sep	21:27	**2***	96.56	-12.12	143	23
12-Sep	20:05	5	99.92	-12.14	101	11
14-Sep	19:25	19	94.28	-12.02	72	0
16-Sep	22:15	15	80.65	-11.78	83	17

Table 2 Larval count records and corresponding theoretical lunar data. * Minimum larval count; ** Maximum larval count; Moon below horizon at observation time highlighted in black.

Date (2011)	Start Time GMT	Larval count	Lunar Phase (100=Full)	Lunar Apparent Magnitude	Lunar Azimuth	Lunar Elevation
18-Sep	21:10	54	61.48	-11.42	51	-1
21-Sep	21:15	85	30.05	-10.49	20	-15
23-Sep	20:50	89	12.82	-9.37	348	-23
26-Sep	21:45	107	0.20	-4.39	316	-32
29-Sep	20:15	130**	7.42	-8.17	258	-14
01-Oct	21:30	125	22.15	-9.98	241	-8
04-Oct	21:30	24	52.56	-11.25	209	12
07-Oct	19:50	4	81.96	-11.86	149	24
09-Oct	21:40	3*	95.04	-12.08	153	35
13-Oct	20:15	9	95.92	-12.10	84	16
16-Oct	19:30	14	74.92	-11.78	45	-3
20-Oct	21:30	14	33.59	-10.75	31	-18
26-Oct	21:35	13	0.06	-1.47	298	-39
01-Nov	22:25	1	38.17	-10.72	249	-6
04-Nov	22:30	0	97.60	-11.57	230	21
08-Nov	22:10	0	0.02	-12.11	179	50

Table 2 Continued.

Larval distribution curve

The 2011 larval glowing season was from 10th July to 1st November. The undulating nature of the larval distribution plot was interesting, with four peaks in total and three troughs (Fig. 2). The first peak had a count of 95, where it was noted that the walk took longer than earlier walks in order to see more accurately the larvae with their sporadic flashes. The second peak had a high point of 118 on 3rd September (a day with a relatively high daytime temperature of 27°C, and 21°C at the time of the count), and the third peak formed by three high readings of 107, 130 and 125 during the very warm spell late in September and early October. Weather conditions were mainly dry during the period of observation.

The troughs in the larval plot were interesting, and their marked nature had been surprising. It was obvious to the recorders at the time that low counts occurred around the full moon, exactly coinciding with the times when counting was more difficult if the moon was shining. Were the larvae glowing and we couldn't see them or were they simply not glowing? Trough records taken when the moon was behind clouds were particularly important, as visibility of the larvae was easier than if the moon was shining. see Table 3 for low count records with three examples in cloudy conditions.

Around 10th August it was thought that the lower readings indicated the end of the larval glowing season, but further monitoring proved this to be incorrect. As the undulating pattern emerged with peaks every month it was thought neces-

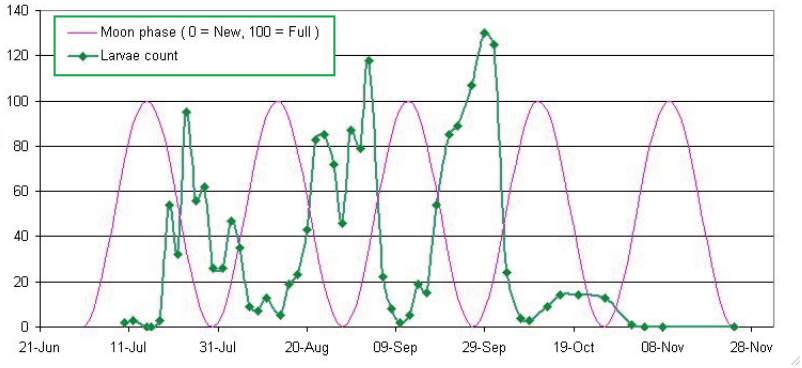

Figure 2 Larval and lunar cycle (2011).

sary to add the phases of the moon on the larval distribution curve to see if such a relationship existed.

Care must be taken with the interpretation of this chart. The seemingly good inverse correlation of the larval pattern with the lunar cycle is very marked, but it could also be argued that the peaks are simply caused by the greater visibility of glow-worms during the new moon, and the troughs caused by difficult viewing conditions during the full moon if the moon was in a clear sky. Cloudy nights were therefore a very important part of the recording, not only because the larvae were easier to count on these nights because of the decreased ambient light intensity, but also because it removed additional counting difficulties near water, such as reflected stars and moonlight reflected in water droplets, as recorded in the

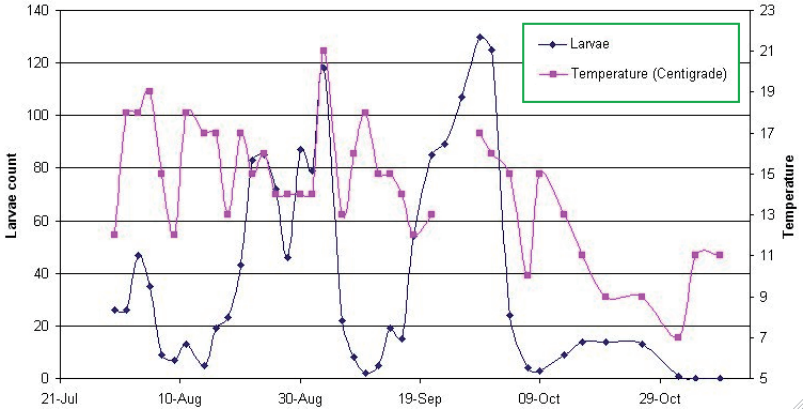

Figure 3 Larval counts and temperature, 2011. Temperature only recorded from 31st July.

Date	No. Larvae	Temperature & conditions	Moon & cloud cover	Time pm BST	Comments
7th Aug	9	15ºC, dry	partial moon obscured by clouds	10:00	
9th Aug	7	12ºC, dry	3/4 moon	10:25	moon made observation difficult
11th Aug*	13	18ºC, dry	no moon	10:45	dark - made observation easier
14th Aug*	5	17ºC	no moon, cloudy	10:15	
8th Sep	8	16 ºC dry	3/4 moon for most of the walk	10:55	moonlight made it more difficult to observe. Previous night was quite cold - reason for the lower numbers?
10th Sep	2	18 ºC, dry	full moon - quite light	10:27	full moon made it difficult to observe
12th Sep	5	15ºC, dry	full moon - but better angle than the night before - but very windy	09:05	some areas were difficult to observe because of the moon and wind (on plants)
7th Oct	4	10ºC, wet, no wind		08:50	couldn't count previous evening - raining. Cold previous night 7 ºC. Noted inaccuracies - difficulty counting in moonlight with moon shining in water droplets & stars reflected in the water 'false low'?
9th Oct *	3	15ºC, dry, windy	no moon but quite light - moon behind clouds	10:40	quite light - but should have been able to see them. Thought they weren't as bright or switched on for as long

Table 3 Excerpt from the records taken during the three troughs. * readings taken when there was a cloud covered moon.

comments on 7th October. If the larvae were responding to ambient light intensity alone the curve should show high counts for both lower ambient light or cloud covered moon conditions. The asterisked counts in Table 3 on 11th and 14th August and 9th October were all taken in cloudy conditions during a full moon, and their low counts clearly indicate that there is some other factor inhibiting the count. Other conditions to be taken into consideration are damp and temperature.

Could variation in temperature have an influence, with the troughs partly due to colder temperatures and the peaks to higher? As can be seen in Fig. 3 a mixed picture emerges because high temperatures coincide with both troughs and peaks, indicating no obvious relationship.

It has been speculated that damp conditions are thought to increase activity of glow-worms because their food source of snails and slugs like damp conditions. Subjective records of these conditions were taken during the season as being dry,

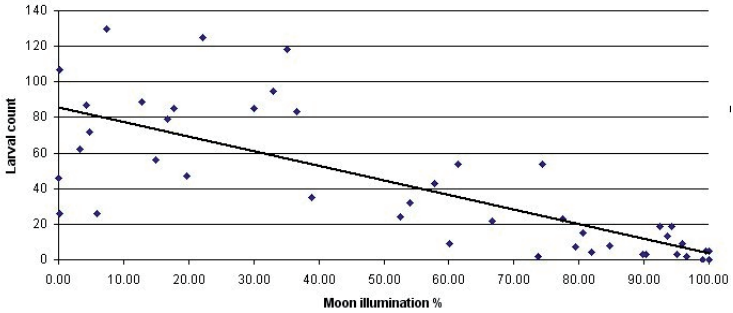

Figure 4 Total larval count/lunar phase (0=New, 100=Full). Three complete Lunar cycles (Data Correlation -0.75).

damp, raining etc. The summer conditions were predominately dry, there was a drought here, with 33 'dry' readings recorded during the larval counting season. Only on 7 occasions during the larval glowing season were there 'damp' conditions, of these 2 coincided with the upward slope before a peak, and 2 coincided with the downward slope after a peak, and one was in the last trough. Only 2 of the 7 the damp readings on 3rd and 24th August produced higher counts than the dry counts on either side. From these records a positive effect of damp on the larval count was not conclusively indicated, indeed the highest counts were achieved in dry conditions.

Given that conditions such as damp and temperature do not appear to have a marked influence on the troughs, what was their cause? Reduced visibility because of the full moon during some of the trough counts as indicated in Table 2, may well have contributed to some of the low readings, but those taken during cloud cover on three of the trough readings are consistent with those taken in the same trough when there was moonlight. Also, on the cloudy nights the observers felt that larvae would have been visible and countable had they been glowing. The reason for troughs in the larval count therefore appears to be predominately caused by the influence of the moon.

The larval activity produced three major peaks during the season as Fig. 2 indicates and there appears to be a good relationship for these peaks and the phases of the moon. To improve confidence in this assumption the larval count data has been plotted against the phase of the moon (Fig.s 4 & 5). The resultant plot shows a good inverse relationship against the moon phase with a reasonable mathematical correlation of -0.75.

Each larval peak falls between a 'full moon - new moon - full moon' cycle and data for each of these cycles has been recorded separately on this plot. A graphical trend line for each cycle has also been added. The results clearly show the required negative trend line for all three sets of data, thus indicating that larval activity

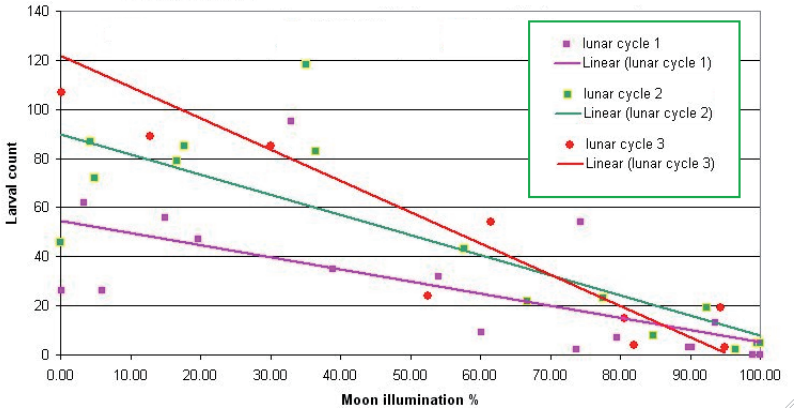

Figure 5 Individual larval count cycles/lunar phase with linear regression. Correlation data cycle 1 = -0.65, cylce 2 = -0.82 and cycle 3 = -0.94.

appears to be dependent on the moon phase, peaking around new moon and being minimal around full moon. Individual correlation of each cycle is shown in this figure and indicates improving synchronization of the larvae with successive moon phases, with cycle 3 having an excellent correlation of -0.94

Whilst the above indicates a larval dependence on the moon it could be argued that it is the lunar light levels rather than the absolute lunar phase that controls events. The lunar light is a very variable factor as the amount of light from the moon depends upon the time of the year with its influence on the moon's elevation, the phase of the moon, the time the larval observations are made and of course the clarity of the sky. It has already been suggested that the larvae are not influenced by ambient light levels as indicated by the few low larval count observations when the moon was present but behind clouds. A more detailed analysis of larval count dependence on ambient light levels is clearly required. No accurate recordings of ground light levels were made during 2011.

As the season was predominantly dry with only a few cloudy days, theoretical levels of lunar light have been researched together with the moon's elevation from the site's location, see Table 2. This allows larval count to be plotted against the brightness of the moon and automatically takes into account such factors as elevation and the phase of the moon (Fig. 6). Included in Fig. 6 are indications of whether the moon is above the horizon at the time and date of the observations.

The resultant plot shows the same monthly link to the moon as would be expected, however there is a marked difference between the sinusoidal nature of the moon's phase curve and the now peaky brightness curve at new moon and the flatter more constant light levels around full moon. The net result of this is that the correlation between larval count and lunar brightness is much degraded producing

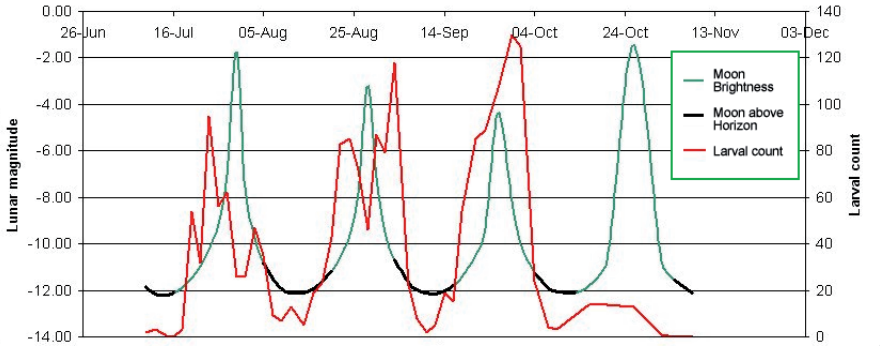

Figure 6 Larval counts/lunar brightness. Correlation 0.38. Maximum lunar birghtness (apparent magnitude) possible -12.74).

a low value of only 0.38. Larval activity therefore is not linked to ambient light levels but seems to be intrinsically synchronized to the mechanical lunar cycle, as indeed are the activities of many other creatures as indicated in the introduction.

Sound and vibration

It was also noted that during the walks the larvae may have reacted to sound or vibration. The second recorder, walking behind the first would see larvae that the first had not seen. Was that because the larvae had responded to the vibration of the first's footsteps, or was this simply due to the timing of the 'flashes'? On another occasion, on calling out after a fall, it was noted that some larvae appeared to switch on as a result of either the sound or the vibration or both. Another event when the larvae seemed to respond to a sudden loud gun shot from a local shoot indicates that they could react to sound alone. Some attempts were made to reproduce this effect but with no success.

Vegetational habitat of the larvae

Many of the larvae were seen on the stems of a bed of sedges in the lake which in October had their 'feet in water'. Presumably they would have had access to the stems earlier in the year when the water level in the lake was low, and then became marooned when the water level rose. This assumes the larvae are not amphibious. Sedge seemed to be a popular location for the glow-worm larvae. Another location where there was a large colony of larvae was in an area of short scrub and *Hypericum* (species not identified) adjacent to the railway embankment.

Discussions and questions

Before attempts to discuss this lunar cycle phenomena two basic questions need to be raised. Firstly, why do the glow-worm larvae 'flash'? This has been the subject of speculation, but in a study by de Cock & Matthysen (2003), the bioluminescence

has been found to have an aposematic signal upon toads (*Bufo bufo*), and studies with firefly larvae (Coleoptera:Lampyridae) also confirm an aposematic signal hypothesis (Underwood et al. 1997). Adults of both species have a range of defence mechanisms (Day 2011), and both larvae have chemical defenses making them unpleasant to taste, and it is suggested (Tyler 2002) that the bioluminescence acts as an aposometric signal to warn predators of this. Plants also contain chemicals to deter being consumed and in the case of palm leaves (Vogt et al. 2002) this has a lunar cycle, because leaves harvested during the full moon exhibit fluctuations in some chemicals which render them more durable than when harvested at other times.

Secondly, why would the luminescence significantly reduce during a full moon? In a book entitled 'The Glow-worm' (2002) Tyler suggests that the flashing starts once ambient light levels fall below a certain threshold, and that the higher light levels on bright moonlit nights may be the reason why they fail to glow, although our observations show that 'flashing' is inhibited even in low light levels at the full moon when cloudy conditions exist. One other possible answer to the lack of bioluminescence activity during the full moon could be to do with predation, either of themselves, or availability of their prey. In a study on bats *Lophostoma silvicolum* who apparently exhibit 'lunar phobia' tendencies, activities of both them and one of their main prey, katydids, were examined with regard to the lunar cycle (Lang et al. 2006). It was found that both bats and katydids were more active during the dark periods associated with the new moon compared with bright periods around the full moon. The article suggests that the causes of lunar phobia is prey availability that it is generally species specific. Little data was found on the feeding habits of the glow-worm larvae's prey, small snails, except that they are more active in damp conditions, and no lunar cyclic links were found. Given the chemical defenses that the larvae possess, a lunar 'phobic' behavior to avoid predation appears to be unnecessary.

The cause of the lunar periodicity of the larvae's bioluminescence is open to speculation, and more work needs to be carried out to confirm the lunar link reported here, together with ideally an examination of other possible causative factors such as prey availability and specific predator avoidance. Bioluminescence is a communication device in insects (Lloyd 1971), and functions other than sexual attraction suggested for it are prey attraction, warning, intimidation of predators, illumination, camouflage, and population regulation. Could inter-species communication through larval bioluminescence be entirely ruled out? For example, could the flashing have a territorial aspect? Another question to pose is exactly how much control over the flashing do the larvae have? Could one aspect of the flashing be an involuntary reaction due to specific feeding conditions? In due course, answers to these questions will no doubt materialize.

Following the interesting effect of the moon phases on the larval count, it was thought desirable to see if female glowing was also influenced by the moon (Fig. 7).

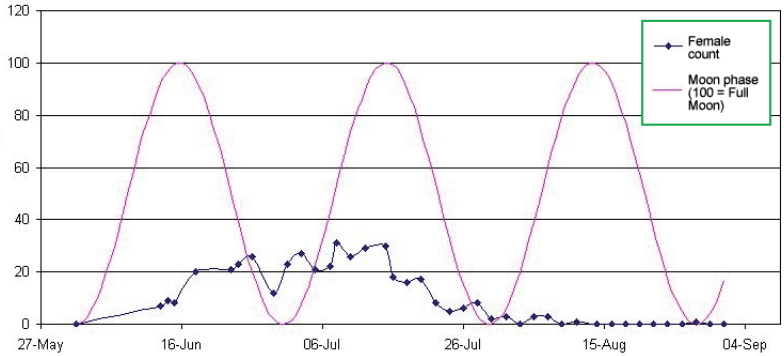

Figure 7 Female glow-worm counts and lunar cycle (2011).

The count distribution was normal but no effect was seen due the moon cycle. The female count spans 2 lunar cycles and appears to be totally uninfluenced by it. The females have such a short glowing season to attract a mate it could be argued that it doesn't make any sense to 'switch off' during the full moon. The females' glow is so bright that it can still be seen in moonlight, so a case for switching off during periods of moonlight is clearly unnecessary.

CONCLUSIONS

These results indicate that there is an inverse correlation between the phase of the moon and the glowing of the larvae. During the full moon larval glowing activity was low, but started to rise immediately following the full moon reaching a peak around the new moon. By contrast the female glowing activity appeared to be unaffected by the lunar cycle.

The effect of the moon on the larvae's bioluminescence was unexpected as was the possible effect of sound and/or vibration. Clearly further measurements in all these areas need to be carried out.

Precise measurements of ambient light levels, air temperatures and humidity during all observations may also provide other relationships with the glow-worm activity.

These results are based upon records taken at a nominally fixed time of the evening, which becomes later in terms of hours after sunset as the season progresses. Further work would be beneficial to record glow-worm activity at a fixed time after sunset or even their activity over the season from dusk till dawn.

ACKNOWLEDGEMENTS

We would like to thank John Tyler for his assistance and comments on the manuscript.

REFERENCES

Bachleitner, W., Kempinger, L., Wülbeck, C., Rieger, D. & Helfrich-Förster, C. (2007) Moonlight shifts the endogenous clock of *Drosophila melanogaster. Proceedings of the National Academy of Sciences of the United States of America* **104** 3538-3543.

Bhattacharjee, C., Bradley, P., Smith, M., Scally, A.J. & Wilson, B.J. (2000) Do animals bite more during a full moon? Retrospective observational analysis. *British Medical Journal* **321** 1559-1561.

Boch, C.A., Ananthasubramaniam, B., Sweeney, A.M., Doyle, F.J. & Morse, D.E. (2011) Effects of Light Dynamics on Coral Spawning Synchrony. *Biological Bulletin* **220** 161-173.

Cutler, W.B. (1980) Lunar and menstrual phase locking. *American Journal of Obstetrics and Gynecology* **137** 834-839.

Dacke, M., Byrne, M.J., Scholtz, C.H. & Warrant, E.J. (2004) Lunar orientation in a beetle. *Proceedings of the Royal Society London Biological Sciences* **271** 361-365.

Dacke, M., Byrne, M.J., Baird, E., Scholtz, C.H. & Warrant, E.J. (2011) How dim is dim? Precision of the celestial compass in moonlight and sunlight. *Philosophical transactions of the Royal Society Biological Sciences* **366** 697-702.

Day, J.C. (2011) Parasites, predators and defence of fireflies and glow-worms. *Lampyrid* **1** 70-102.

de Cock, R. & Matthysen, E. (2003) Glow-worm larvae bioluminescence (Coleoptera: Lampyridae) operates as an aposematic signal upon toads (*Bufo bufo*). *Behavioral Ecology* **14** 103-108.

Fleissner, G., Schuchardt, K., Neumann, D., Bali, G. & Falkenberg, G. (2008) A lunar clock changes shielding pigment transparency in larval ocelli of *Clunio marinus. Chronobiology International* **25** 17-30.

Kaiser, T.S., Neumann, D. & Heckel, D.G. (2011) Timing the tides: genetic control of diurnal and lunar emergence times is correlated in the marine midge *Clunio marinus. BMC Genetics* **12** 49.

Lang, A.B., Kalko, E.K., Römer, H., Bockholdt, C. & Dechmann, D.K. (2006) Activity levels of bats and katydids in relation to the lunar cycle. *Oecologia* **146** 659-666.

Lieber, A.L. (1978) Human aggression and the lunar synodic cycle. *Journal of Clinical Psychiatry* **39** 385-392.

Lillie, T.H., Kline, D.L. & Hall, D.W. (1988) Host-seeking activity of *Culicoides spp. (Diptera: Ceratopogonidae)* near Yankeetown, Florida. *Journal of American Mosquito Control Association* **4** 485-493.

Lloyd, J.E. (1971) Bioluminescent communication in Insects. *Annual Review of Entomology* **16**: 97-122.

Mikulecky, M. & Zemek, R. (1992) Does the moon influence the predatory activity of mites? *Experientia* **48** 530-532.

Mikulecky, M. & Bounias, M. (1997) Worker honeybee hemolymph lipid composition and synodic lunar cycle periodicities. *Brazilian Journal of Medical and Biological Research* **30** 275-279.

Mohssine, E.H., Bounias, M. & Cornuet, J.M. (1990) Lunar phase influence on the glycemia of worker honeybees. *Chronobiologia* **17** 201-207.

Neumann, D. (1989) Circadian components of semilunar and lunar timing mechanisms. *Journal of Biological Rhythms* **4** 285-294.

Rahman, M.S., Morita, M., Takemura, A. & Takano, K. (2003) Hormonal changes in relation to lunar periodicity in the testis of the forktail rabbitfish, *Siganus argenteus*. *General and Comparative Endocrinology* **131** 302-309.

Rahman, M.S., Kim, B.H., Takemura, A., Park, C.B. & Lee, Y.D. (2004) Effects of moonlight exposure on plasma melatonin rhythms in the seagrass rabbitfish, *Siganus canaliculatus*. *Journal of Biological Rhythms* **19** 325-334.

Souza, N.A., Andrade-Coelho, C.A., Silva, V.C., Peixoto, A.A. & Rangel, E.F. (2005). Moonlight and blood-feeding behaviour of *Lutzomyia intermedia* and *Lutzomyia whitmani* (Diptera:Psychodidae:Phlebotominae), vectors of American cutaneous leishmaniasis in Brazil. *Memórias do Instituto Oswaldo Cruz* **100** 39-42.

Takemura, A., Susilo, E.S., Rahman, M.D. & Morita, M. (2004) Perception and possible utilization of moonlight intensity for reproductive activities in a lunar-synchronized spawner, the golden rabbitfish. *Journal of Experimental Zoology. Part A: Comparative Experimental Biology* **301** 844-851.

Thakur, C.P. & Sharma, D. (1984) Full moon and crime. *British Medical Journal* **289** 1789-1791.

Wakefield, C.B. (2010) Annual, lunar and diel reproductive periodicity of a spawning aggregation of snapper *Pagrus auratus (Sparidae)* in a marine embayment on the lower west coast of Australia. *Journal of Fish Biology* **77** 1359-1378.

Tyler,J. (2002) The Glow-worm. Lakeside, Sevenoaks.

Underwood, T.J., Tallamy, D.W. & Pesek, J.D. (1997) Bioluminescence in firefly larvae: A test of the aposematic display hypothesis (Coleoptera: Lampyridae). *Journal of Insect Behavior* **10** 365-370.

Vogt, K.A., Beard, K.H., Hammann, S., Palmiotto, J.O., Vogt, D.J., Scatena, F.N. & Hecht, B.P. (2002) Indigenous knowledge informing management of tropical forests: the link between rhythms in plant secondary chemistry and lunar cycles. *Ambio* **31** 485-490.

Youthed, G.J. & Moran, V.C. (1969) The lunar-day activity rhythm of myrmeleontid larvae. *Journal of Insect Physiology* **15** 1259-1271.

Zimecki, M. (2006) The lunar cycle: effects on human and animal behavior and physiology. *Postępy Higieny i Medycyny Doświadczalnei* (Online) **60** 1-7.