The size variation and age ratios found within the larval population of the Glow Worm during Autumn

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The research is based around data obtained from larvae at Clipstone Old Quarter, an area of commercial forestry within the confines of Sherwood Forest, Nottinghamshire.

This publication sees some changes to the theories and proposals originally published in 2012 and in some instances, we are happy that we now have enough evidence or data, to conclude some aspects of our research.

Some of the text remains the same as found on the website www.eakringbirds.com, but much has been re-written to incorporate the data and findings from our continued work over the course of 2013.

1.0 Introduction to Project 2: Phase 2. 2013

Project 2: Phase 2. 2013 was conducted by Trevor and Dilys Pendleton (TDP), based at Market Warsop, Nottinghamshire. We were once again aided by Martin Dale (MD) based in Nottingham, who assisted us with field survey work and also provided important comparison data based on observations of captive larvae. Martin is also co-author and researcher of Project 1: Phase 1. 2012 "Some notes and observations on the bioluminescence exhibited by the larva of the Glow Worm (*Lampyris noctiluca*) in captivity".

The focus for our Project 2: Phase 1. 2012 research, was to continue the same work commenced back in 2012, by once again collating as much larval size range data from our study colony at Clipstone Old Quarter in Sherwood Forest, during the late Summer and Autumn of 2013.

The aims of this research are to try and accurately determine the following aspects of Glow Worm larval activity.

- **The number of active larvae present during the latter months of the year (post adult glowing season)**
- **The period of larval activity during the Autumn and early Winter months**
- **Peak time for greatest larval activity**
- **The range of larval sizes present on site**
- **The usual hunting range of larvae in relation to forest paths and tracks**
- **Activity of larvae in relation to ground temperature**

1.1 Recording methodology and data collection

Recording larvae in the wild is time consuming, sometimes with little success for the number of hours spent in the field collecting data. The amount of success was largely dependent on the time of the year, with August and September providing the best results in terms of the amount of larvae recorded and data collected. Temperature also proved to be an important factor and site visits in late Autumn were confined to cloudy or moonless nights wherever possible and ideally when the temperature was 8°C or above. Clear nights with a near full moon provided very limited success.

The process of surveying for larvae was simple, with the observers walking slowly along forest paths and tracks until the bioluminescent glow of a larva was seen. The larva would be located with the aid of torchlight and its length measured, before being returned to the place of capture. Other similar larval measuring techniques adopted by other researchers, have involved measuring the width of the larva rather than length, but we are satisfied that our measuring techniques are accurate after measuring over 450 larvae during the course of four successive Springs and over 150 in Autumn 2012 and that the data is true.

1.2 Site map and survey sections

The image of the Clipstone Old Quarter survey route on the following page, measures approximately 1,300 metres from north to south (A-D).The two yellow dots marked T1 and T2, indicate the on-site locations of ground

temperature measurements, with T2 being the highest of the two points. The central grid reference for the site is SK 60549 67012.

1.3 A brief overview of the study colony history

The study colony at Clipstone Old Quarter is situated within Sherwood Forest in Nottinghamshire and although assigned SSSI status, the site does not fall within the Sherwood Forest National Nature Reserve boundary.

We have actively studied the number of adult female Glow Worms at this colony since 2008, but intensified our coverage in 2009 and have not missed a visit during the adult glowing season since. Coupled with our Spring larval surveying, we have accumulated well over 500 evenings worth of larval and adult data, probably making this the most intensely studied and recorded Glow Worm colony in the UK.

Despite being located in the middle of Nottinghamshire, this colony has proved to be one of the earliest UK sites for Glow Worms. We believe that this is down to observer coverage rather than females appearing genuinely early, as the site does not seem to have a particularly warm climate.

Another interesting aspect of the site is the consistently high numbers of female Glow Worms recorded each year (see Table 01) producing a total of 2,278 females between 2009 and 2012 and has yet to produce the occasional poor year often recorded at other UK sites.

The fact that the adult Glow Worm population at Clipstone Old Quarter has done so well each year is especially interesting, considering that one other Glow Worm colony at nearby Sherwood Heath SSSI, has seen a considerable decrease in the number of adults present over the same time period.

Counts of over 200 females in 2008, have recently dropped down to just single females in 2010, 2011 and 2012, while three other nearby colonies are also struggling to survive with very small numbers of females annually.

There are several factors that could have influenced the decline in Glow Worm numbers at Sherwood Heath SSSI, including dryness of habitat during the Summer, subsequent lack of available prey items and the use of herbicides to control Bracken spread using heavy machinery.

Clipstone Old Quarter has so far escaped the use of chemical sprays and is generally less susceptible to over-drying, being protected from wind and having areas of shade provided by mature Pine plantations and areas of deciduous trees. The site can become dry during periods of exceptionally sunny weather, but any effects have not been visible among the adult Glow Worm population in recent years.

1.4 Assigning ages to larvae

Ageing Glow Worm larvae is not a simple process and unless larvae are reared in captivity from egg to adult, then assigning the correct calendar year (cy) to a larva, is somewhat open to conjecture and recorder interpretation. Perhaps the real difficulty is created by the fact that some larvae could certainly reach adulthood within 12-14 months, if conditions were right and food was caught regularly. Other larvae could possibly take as long as three years before reaching the pupation stage. Growth is of course dependent on the larva's ability to find food.

We based our Project 2: Phase 1. 2012 data on the assumption that most Glow Worm larvae have a more or less two year period of development, or at least over-winter twice. This would mean that larvae found during both Spring and Autumn 2012, would generally originate from eggs laid by females in 2010 and 2011. Hence throughout 2012, larvae hatched in 2010 would be in their second calendar year (2cy) while 2011 larvae would be in their first calendar year (1cy).

In Project 2: Phase 1. 2012, we proposed three possible examples of larval life cycles, based over different lengths of larval development.

1cy larval cycle

1. A mated female lays eggs in late May 2010.
2. Eggs hatch into 4mm larvae around late June 2010.
3. Larva feeds well and grows from 4-17mm during Summer of 2010.
4. Larva over-winters once from 2010/2011.
5. Larva completes growth and becomes adult in late July 2011.

2cy larval cycle

1. A mated female lays eggs in early June 2010.
2. Eggs hatch into 4mm larvae around late June or mid-July 2010.
3. Larva possibly grows to 7-10mm before over-wintering from 2010/2011.
4. Larva grows from 7-10mm - 17-26mm during Summer of 2011.
5. Larva over-winters for second time from 2011/2012.
6. Larva becomes adult in Spring/Summer 2012.

2cy - 3cy larval cycle

1. A mated female lays eggs in mid-July 2010.
2. Eggs hatch around mid/late August into 4mm larvae.
3. Larva feeds and grows, reaching 6-7mm before over-wintering from 2010/2011.
4. Larva continues to grow during Summer 2011, possibly reaching 15-20mm.
5. Larva over-winters for second time from 2011-2012.
6. Larva either completes growth and becomes adult in Spring 2013 or
7. Continues development and growth before over-wintering for a third time from 2012/2013, becoming adult in Spring 2013.

The proposed larval cycles are now believed to be of little value, due to the considerable variability in growth found by rearing larvae in captivity from 2012-2013. There are just too many influencing factors to consider.

1.5 Intermediate age range larvae

In Project 2: Phase 1. 2012, we clearly placed too much emphasis on relating larval size to age and it is unlikely that we will be continuing much further with this line of research.

Surveying in Spring 2013 provided us with some valuable data, enabling us to more or less prove that (aside from some individual exceptions) the majority of larvae falling within the 16-18mm 'intermediate' age range in April and May, and previously expected to remain as larvae till the following Spring, would go on to produce adult males the same year. We randomly collected six larvae measuring between 15mm and 18mm in length and kept them in captivity, but at outdoor temperatures. They were expected to remain as larvae for a further year, but all quickly pupated and produced males.

In the larval size charts, we originally categorised larvae into three groups or age ranges. These were 1cy (9mm-15mm), intermediate (16mm-18mm) and 2cy (19mm-28mm). We proposed that intermediate larvae were those larvae whose length placed them in a grey area between both calendar year groupings and that they could be either well developed 1cy larvae or poorly developed 2cy larvae. Alternatively, we believed that they could be 2cy larvae, with a third year of growth to complete before pupation.

Although it is possible that intermediate larvae make up a proportion of late emerging females in the second half of July, it now seems likely that (in Spring or late Autumn at least) that most intermediate larvae develop into adult males. It seems that the majority of larvae recorded nocturnally in the Autumn, have little growth to complete before pupation the following Spring. Therefore, in all the following larval size charts, we are categorizing larvae purely by size, rather than categorize them to a specific calendar year.

1.6 The effects of annual rainfall and temperature on larval size and over-wintering success

In Table 02 we have once again looked at the period of April 1st - 7th of each year, taken the average larval sizes found along one stretch of cycle track (sections A, B, C and D on the site map) and compared them with the recorded rainfall between the months of April to August & September to March. Larvae found during late afternoon and early evening surveys, are now believed to be larvae in the pre-pupation stage, possibly feeding once more before pupation takes place.

The rainfall is based on Met Office data for Waddington in Lincolnshire, which is the nearest weather station to the Sherwood Forest area that lists historical rainfall data. In the table, we have divided the 12 months into two periods, just to see if the data held up for the preceding Summer, as it seems to do with the preceding Winter.

Table 01. Average larval sizes and rainfall during Spring 2009 - 2013

Year	Total Rainfall	Summer period	Rainfall	Winter period	Rainfall	Survey period	Size (Avg)
2007	770.90mm	Apr 07 - Aug 07	473.50mm	Sep 07 - Mar 08	325.90mm		
2008	725.00mm	Apr 08 - Aug 08	312.80mm	Sep 08 - Mar 09	346.50mm		
2009	558.60mm	Apr 09 - Aug 09	261.30mm	Sep 09 - Mar 10	337.70mm	April 8-14 2009	21.14mm/14
2010	647.80mm	Apr 10 - Aug 10	273.80mm	Sep 10 - Mar 11	302.90mm	April 8-14 2010	19.58mm/17
2011	423.50mm	Apr 11 - Aug 11	198.80mm	Sep 11 - Mar 12	224.20mm	April 8-14 2011	19.19mm/31
2012	826.80mm	Apr 12 - Aug 12	444.00mm	Sep 12 - Mar 13	427.80mm	April 8-14 2012	19.66mm/9
2013	517.70mm	Apr 13 - Aug 13	198.30mm	Sep 13 - Mar 14		April 8-14 2013	17.11mm/9

Figure after the forward slash, show the sample total, e.g. 14 larvae, 17 larvae etc.

There did originally seem to be some correlation between Spring larval sizes and the amount of rainfall during the preceding months/year based on the data we had up until 2012, but this now seems less so, especially after the average larval size decreased even further in Spring 2013, following a very wet 2012.

Reductions in the number of larva recorded during periods of very dry weather continues to be noted, whether during diurnal surveys in Spring, or nocturnal surveys during the Summer and Autumn. The effects of dehydration on the larval populations at very dry sites such as nearby Sherwood Heath SSSI, has been more evident than it has at Clipstone Old Quarter, and the contrasting numbers of adults found at both sites since 2008 (even with a

reduction in adults at Clipstone Old Quarter) certainly seem to indicate this.

Harvesting Pines at Clipstone Old Quarter during the Winter of 2013-2014, is therefore likely to have a significant impact on the study site's future Glow Worm population. By opening up the site to increase the amount of lowland heath, will undoubtedly leave it prone to becoming much drier.

The cold Spring of 2013, meant that no larval size data was recorded until the second week of April, breaking the run of data collected between April 1-7th.

Quite remarkably and despite some evidence to suggest larval size might be linked to the amount of rainfall recorded (hence greater food availability) during the previous year, the average larval length between April 8-14th 2013, was lower despite a very wet 2012.

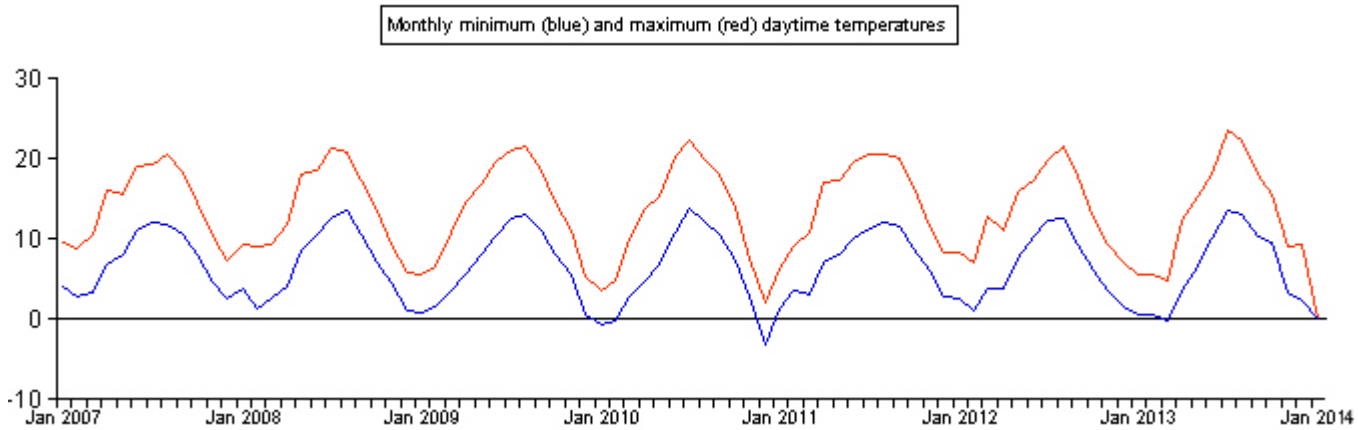
Table 02. Larval size averages during Spring 2009-2013

	Glow Worm larval size/average per year					
Week/period	**2009**	**2010**	**2011**	**2012**	**2013**	**Wkly avg**
March 22-31	.....	.....	18.03mm/27	21.16mm/6	.....	19.59mm
April 1-7	23.33mm/3	21.27mm/13	18.64mm/70	19.00mm/5	.....	20.56mm
April 8-14	21.14mm/14	19.58mm/17	19.19mm/31	19.66mm/9	17.11mm/9	19.89mm
April 15-21	20.45mm/10	20.78mm/18	19.78mm/53	23.20mm/5	18.34mm/34	21.05mm
April 22-29	23.32mm/25	18.74mm/53	19.97mm/39	18.77mm/9	18.61mm/25	20.20mm
April 30-May 6	22.95mm/20	23.20mm/5	21.87mm/8	20.95mm/22	19.85mm/16	22.24mm
May 7-14	22.08mm/17	23.25mm/4	.....	22.30mm/10	21.62mm/21	20.72mm
May 15-22	.....	19.66mm/6	.....	.....	21.62mm/8	20.64mm
						Total avg
Spring average	22.21mm/89	20.92mm/116	19.58mm/228	20.45mm/66	19.52mm/103	20.53mm/602
Total females	385	502	792	599	495	.....

The decrease in average larval length has been dramatic, with larvae found to be over 5mm shorter in Spring 2013 than in Spring 2009. Dehydration means larvae become lethargic and unable to hunt successfully. Slugs and Snails are likewise affected by periods of adversely dry weather.

Nocturnal surveying has also revealed that larvae are reluctant to hunt during periods of rain and will usually wait sometime until after the rain has stopped. This effectively also reduces the larva's ability to find food, at least for a time, although hunting is more likely to be successful once it commences.

Figure 01. The monthly minimum and maximum daytime temperatures 2007 - 2013



On August 26th 2013, we noted during nocturnal surveying that with the general ground conditions continued to be very dry, many larvae appeared very thin, with no signs of having fed recently.

The very dry weather continued until September 6th, when a new site record count of 48 larvae came after the first day's rain for several weeks. There were signs that some larvae had finally either taken on water or had fed.

Although the mean Winter temperature could have some effect on the over-wintering success of larvae, larval ability to find enough food during the Autumn, is probably the most important factor governing over-wintering success rates.

In Project 2: Phase 1. 2012 last year, we proposed that larvae may hunt on mild nights, even during Winter. However, our work in conjunction with Martin Dale, suggests that larvae remain largely inactive, even if replicating temperatures similar to those of Spring, Summer and Autumn. Martin did try increasing the amount of light to young larvae kept in captivity and this did prove to be more successful.

2.0 Summary and review of larval size range data from Spring 2009 - 2013

We have again decided to reproduce the larval size data recorded since 2009.

Due to us now believing that Glow Worm larvae cannot be categorised in to age groups purely by size accurately enough, the following larval size charts are now slightly different to those of last year. We also believe that, as this is ongoing scientific research, anyone not having seen or read the data from Project 2: Phase 1. 2012, will still have all the information needed without having to read our initial findings.

Sections 2.1 - 2.6 deal purely in larval size data obtained during our diurnal surveys.

Nocturnal survey data is produced later.

2.1 Spring 2009 larval size data (diurnal)

Table 03. The average larval size ranges recorded during Spring 2009

	9mm-15mm larval size ranges	Intermediate	19mm-28mm larval size ranges
March	N/A	N/A	N/A
April	15.00mm/1	16.76mm/8	22.42mm/46
May	14.00mm/1	18.00mm/2	23.81mm/35

Table 04. Diurnal Glow Worm larval size ranges found during April 2009

	9mm-15mm larval size ranges							Intermediate			19mm-28mm larval size ranges									
Section	9mm	10mm	11mm	12mm	13mm	14mm	15mm	16mm	17mm	18mm	19mm	20mm	21mm	22mm	23mm	24mm	25mm	26mm	27mm	28mm
A							1	2				1		1	1	2	2	1	1	
B										1		1	2		1	1	2	3		
C									1	2				1	3					
D								1		1	1	2	1	7	6	3	2	1		
	9mm-15mm larval size ranges 2.00%							Int 16.00%			19mm-28mm larval size ranges 82.00%									
Total %	0.00	0.00	0.00	0.00	0.00	0.00	1.81	5.45	1.81	7.27	1.81	7.27	5.45	16.36	20.00	10.90	10.90	9.09	1.81	0.00

A total of 94 larvae were recorded and measured during the Spring, with an early record of a 22mm larva found with prey under bark on 09/03/09.

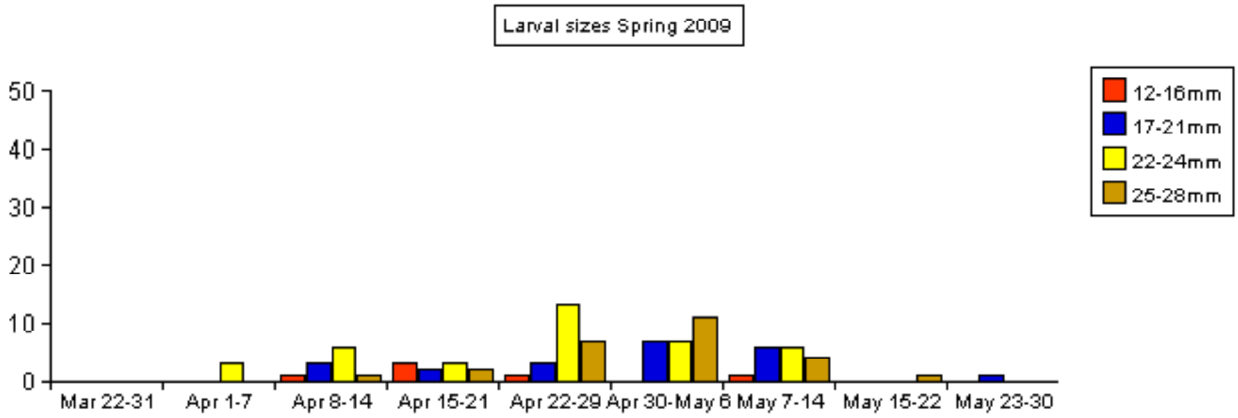
Table 05. Diurnal Glow Worm larval size ranges found during May 2009

	9mm-15mm larval size ranges							Intermediate			19mm-28mm larval size ranges									
Section	9mm	10mm	11mm	12mm	13mm	14mm	15mm	16mm	17mm	18mm	19mm	20mm	21mm	22mm	23mm	24mm	25mm	26mm	27mm	28mm
A													2		1	2	3			
B						1								1	2	1	3			
C										1					1		3	1		
D										1		7	1	1	3	1	1	1		
	9mm-15mm larval size ranges 3.00%							Int 5.00%			19mm-28mm larval size ranges 92.00%									
Total %	0.00	0.00	0.00	0.00	0.00	2.63	0.00	0.00	0.00	5.26	0.00	18.42	7.89	5.26	18.42	10.52	26.31	5.26	0.00	0.00

Tables 06 and 07 show the larval growth rate during April and May 2009. Note the fewer intermediate larvae recorded during May and the recorded increase in larger larval size, which is evident through the higher percentage of larger larvae from the total number of larvae recorded.

Figure 02 shows the larval sizes grouped into four size categories of 12-16mm, 17-21mm, 22-24mm and 25-28mm.

Figure 02. Larval size and activity profile in Spring 2009



Apart from helping to illustrate larval growth throughout Spring 2009, the peak dates for larval activity are also shown to have occurred between April 22nd and May 14th. Two larvae were subsequently found on 19/05/09 and 22/05/09 and the first adult females to appear, were two on 27/05/09.

2.2 Spring 2010 larval size data (diurnal)

Table 06. The average larval size ranges recorded during Spring 2010

	9mm-15mm larval size ranges	Intermediate	19mm-28mm larval size ranges
March	N/A	N/A	N/A
April	14.80mm/15	16.76mm/25	22.42mm/48
May	15.00mm/1	17.33mm/3	23.81mm/11

A total of 103 larvae were recorded from sections A, B, C and D. The first of the year were two on 04/04/10, found in sections L (not used in the data calculations) and in D. Larvae were then found regularly from 06/04/10, including notable counts of ten on both 23/04/10 and 25/04/10.

Table 07. Diurnal Glow Worm larval size ranges found during April 2010

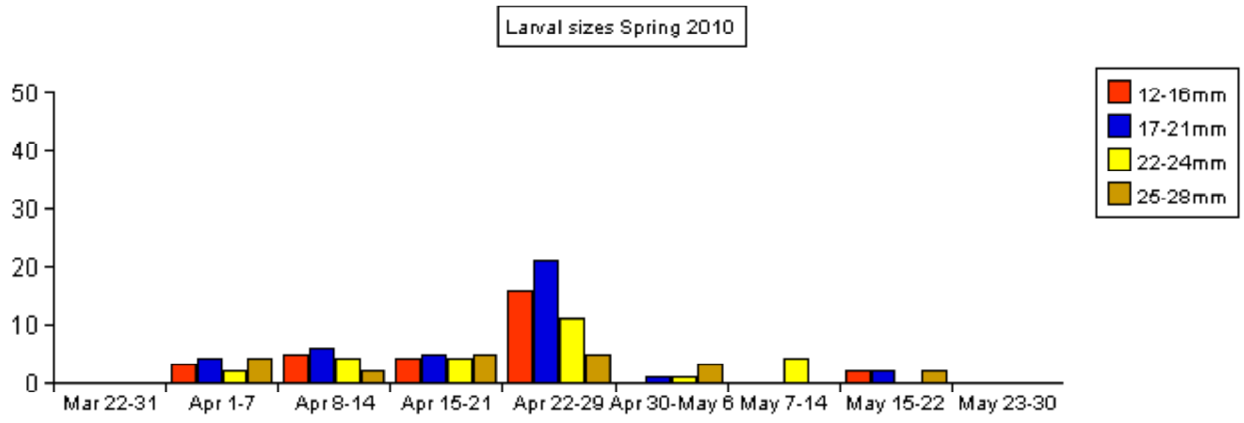
	9mm-15mm larval size ranges							Intermediate			19mm-28mm larval size ranges									
Section	9mm	10mm	11mm	12mm	13mm	14mm	15mm	16mm	17mm	18mm	19mm	20mm	21mm	22mm	23mm	24mm	25mm	26mm	27mm	28mm
A							1	1	1	2	1	2		2		3	1	1		
B							6	4		3	4	2	1		3	1	4			
C							1		2	1	1	2	2	1	1	1	2		1	
D					1	1	5	8	2	1	2	3	1			2	2	1		1
	9mm-15mm larval size ranges 16.00%							Int 29.00%			19mm-28mm larval size ranges 55.00%									
Total %	0.00	0.00	0.00	0.00	1.14	1.14	14.94	14.94	5.74	8.04	9.19	10.34	4.59	3.44	4.59	8.04	10.34	2.29	1.14	1.14

Table 8. Diurnal Glow Worm larval size ranges found during May 2010

	9mm-15mm larval size ranges							Intermediate			19mm-28mm larval size ranges									
Section	9mm	10mm	11mm	12mm	13mm	14mm	15mm	16mm	17mm	18mm	19mm	20mm	21mm	22mm	23mm	24mm	25mm	26mm	27mm	28mm
A							1										1			
B																1	3	1		
C																1				
D								1		2	1			1	1	1				
	9mm-15mm larval size ranges 7.00%							Int 20.00%			19mm-28mm larval size ranges 73.00%									
Total %	0.00	0.00	0.00	0.00	0.00	0.00	6.66	6.66	0.00	13.33	6.66	0.00	0.00	6.66	6.66	20.00	26.66	6.66	0.00	0.00

One difference between 2010 and 2009 was the higher numbers of small size range and intermediate larvae recorded during April (see Table 08). But a comparison with the larval size and activity profiles in Figures 03 and 02, shows a very pronounced peak in the number of larvae recorded between April 22nd and 29th.
The first adult females appeared on 24/05/10, a few evenings earlier than in 2009.

Figure 03. Larval size and activity profile in Spring 2010



2.3 Spring 2011 larval size data (diurnal)

Table 09. The average larval size ranges recorded during Spring 2011

	9mm-15mm larval size ranges	Intermediate	19mm-28mm larval size ranges
March	14.37mm/8	17.00mm/5	20.20mm/15
April	14.65mm/20	17.03mm/58	21.04mm/104
May	N/A	18.00mm/1	23.75mm/4

But after the last of the remaining snow melted in early January, the remainder of the Winter became mild and dry. The favourable weather meant it was suitable for surveying to begin earlier than it had in 2009 and 2010.

A good amount of valuable larval size data was collected and an accurate picture of the increases in larval size between March and May is apparent in Tables 12, 13 and 14. Note the increase in intermediate size larvae during April in Table 13. 2011 proved to be exceptional for numbers of Spring larvae, eventually providing a total of 214 larvae.

Table 10. Diurnal Glow Worm larval size ranges found during March 2011

	9mm-15mm larval size ranges							Intermediate			19mm-28mm larval size ranges									
Section	9mm	10mm	11mm	12mm	13mm	14mm	15mm	16mm	17mm	18mm	19mm	20mm	21mm	22mm	23mm	24mm	25mm	26mm	27mm	28mm
A							1				1	1								
B					1	1	2		1		1	1								
C											2						1			
D						2	1	1	2	1	3	2	2		1					
	9mm-15mm larval size ranges 29.00%							Int 18.00%			19mm-28mm larval size ranges 53.00%									
Total %	0.00	0.00	0.00	0.00	3.57	10.71	14.28	3.57	10.71	3.57	25.00	14.28	7.14	0.00	3.57	0.00	3.57	0.00	0.00	0.00

Table 11. Diurnal Glow Worm larval size ranges found during April 2011

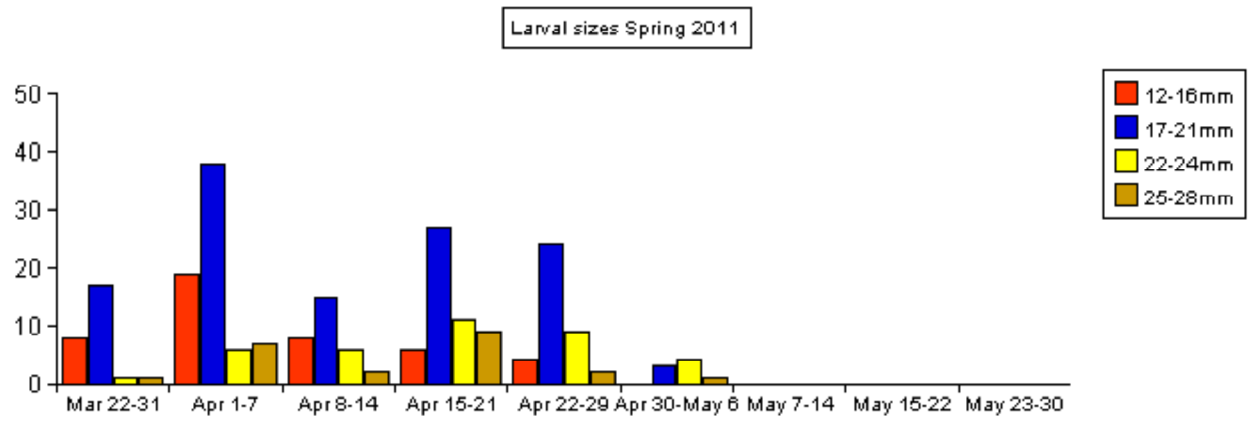
	9mm-15mm larval size ranges							Intermediate			19mm-28mm larval size ranges									
Section	9mm	10mm	11mm	12mm	13mm	14mm	15mm	16mm	17mm	18mm	19mm	20mm	21mm	22mm	23mm	24mm	25mm	26mm	27mm	28mm
A							1		1	3	2	8		1	1		2		1	
B							5	1	3	3	5	8	3	4	5	3	3	1	1	
C							1	1	1	2	2	1					1		1	
D					3	1	9	16	14	13	8	16	10	8	3	2	4			
	9mm-15mm larval size ranges 11.00%							Int 31.00%			19mm-28mm larval size ranges 58.00%									
Total %	0.00	0.00	0.00	0.00	1.61	0.53	8.60	9.67	10.21	11.29	9.13	17.74	6.98	6.98	4.83	2.68	5.37	0.53	1.61	0.00

Table 12. Diurnal Glow Worm larval size ranges found during May 2011

	9mm-15mm larval size ranges							Intermediate			19mm-28mm larval size ranges									
Section	9mm	10mm	11mm	12mm	13mm	14mm	15mm	16mm	17mm	18mm	19mm	20mm	21mm	22mm	23mm	24mm	25mm	26mm	27mm	28mm
A																				
B													1			1				
C																				
D										1					1				1	
	9mm-15mm larval size ranges 0.00%							Intermediate 20.00%			19mm-28mm larval size ranges 80.00%									
Total %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.00	0.00	0.00	20.00	0.00	20.00	20.00	0.00	0.00	20.00	0.00

The larval season was over very suddenly in early May, with a single larvae recorded on 03/05/11 and then four on 05/05/11. The graph in Figure 04 illustrates well the very early season in 2011. Larval growth in late March and through April is clearly shown by the differing ratios of 12-16mm larvae to 17-21mm larvae. Notable in 2011 is the high number of 17-21mm range larvae, compared to both previous years.

Apart from the much higher numbers, the ratio differences between the four larval sizes ranges in 2011 and both 2009 and 2010 are staggeringly contrasting. New record counts were reached on several dates, ultimately peaking at 22 larvae on 05/04/11. But double figure counts were also achieved on seven other dates. With continuing warm and dry weather, it was not surprising that female Glow Worms also appeared very early, with the first three appearing on 13/05/11.



2.4 Spring 2012 larval size data (diurnal)

Table 13. The average larval size ranges recorded during Spring 2012

	9mm-15mm larval size ranges	Intermediate	19mm-28mm larval size ranges
March	N/A	17.00mm/3	23.25mm/4
April	14.50mm/6	16.92mm/9	22.00mm/24
May	N/A	17.50mm/2	22.00mm/20

Very mild weather at the end of February produced two larvae on our first visit on 28/02/12. Hopes were then high, but several further surveys along sections A, B, C and D in early March, all proved negative. Although a third larva was found on 11/03/12, it wasn't until 22/03/12 that regular surveying commenced, but the number of larvae recorded was low and gave cause for concern that the resulting adult glowing season would actually be poor. A count of 11 larvae on 30/04/12, raised hopes that our estimates would be wrong, but this remained our only double-figure larval count of the Spring.

Table 14. Diurnal Glow Worm larval size ranges found during March 2012

	9mm-15mm larval size ranges							Intermediate			19mm-28mm larval size ranges									
Section	9mm	10mm	11mm	12mm	13mm	14mm	15mm	16mm	17mm	18mm	19mm	20mm	21mm	22mm	23mm	24mm	25mm	26mm	27mm	28mm
A																				
B										1									1	
C																				
D								1	1		1	1							1	
	9mm-15mm larval size ranges 0.00%							Int 43.00%			19mm-28mm larval size ranges 57.00%									
Total %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.28	14.28	14.28	14.28	14.28	0.00	0.00	0.00	0.00	0.00	0.00	28.57	0.00

Table 15. Diurnal Glow Worm larval size ranges found during April 2012

	9mm-15mm larval size ranges							Intermediate			19mm-28mm larval size ranges									
Section	9mm	10mm	11mm	12mm	13mm	14mm	15mm	16mm	17mm	18mm	19mm	20mm	21mm	22mm	23mm	24mm	25mm	26mm	27mm	28mm
A							1		1		1				1		1		1	
B								1	1	1			1		1	2			2	
C					1	1					1		1							
D							3		3	2	4	2	2	3		1				
	9mm-15mm larval size ranges 15.00%							Int 23.00%			19mm-28mm larval size ranges 62.00%									
Total %	0.00	0.00	0.00	0.00	2.56	2.56	10.25	2.56	12.82	10.25	15.38	5.12	10.25	7.69	5.12	7.69	2.56	0.00	7.69	0.00

Table 16. Diurnal Glow Worm larval size ranges found during May 2012

	9mm-15mm larval size ranges							Intermediate			19mm-28mm larval size ranges									
Section	9mm	10mm	11mm	12mm	13mm	14mm	15mm	16mm	17mm	18mm	19mm	20mm	21mm	22mm	23mm	24mm	25mm	26mm	27mm	28mm
A										1									1	1
B												1	1	1	1	2				
C													2		1		1			
D									1			1	1	1	3	1	1			
	9mm-15mm larval size ranges 0.00%							Int 9.00%			19mm-28mm larval size ranges 91.00%									
Total %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.54	4.54	0.00	9.09	18.18	9.09	18.18	13.63	9.09	0.00	4.54	4.54

Figure 05. Larval size and activity profile in Spring 2012

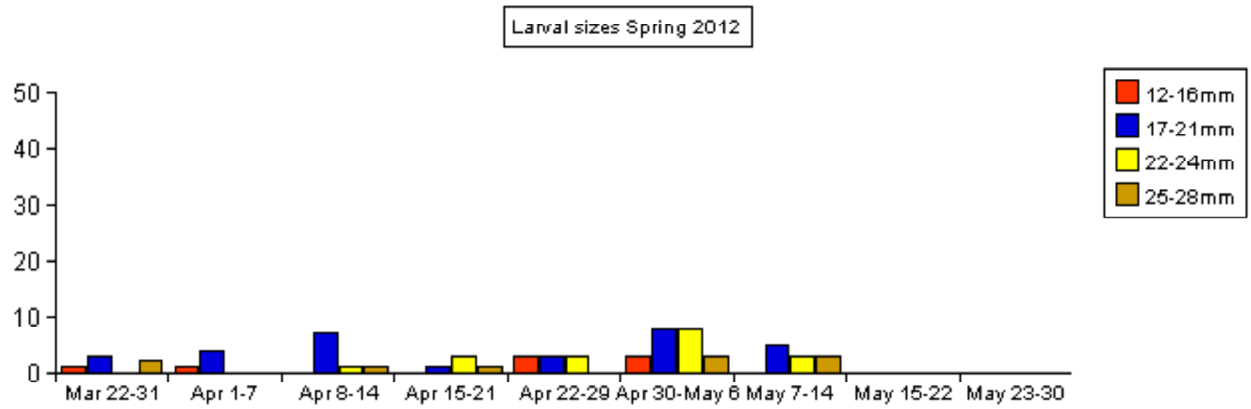


Figure 05 shows the larval size and activity profile for Spring 2012. There was a return to peak larval numbers being more in line with that of 2009 and 2010 (the last week of April) and in many ways, the activity profile is quite similar to that produced in 2009, although the number of larvae is less. Length measurements for 70 larvae were collected, which includes the two February larvae. Adult females appeared from 30/05/12.

2.5 Spring 2013 larval size data (diurnal)

Table 17. The average larval size ranges recorded during Spring 2013

	9mm-15mm larval size ranges	Intermediate	19mm-28mm larval size ranges
March	N/A	N/A	N/A
April	15.00mm/9	17.12mm/49	22.45mm/23
May	15.00mm/7	17.28mm/14	22.04mm/24

Table 18. Diurnal Glow Worm larval size ranges found during April 2013

	9mm-15mm larval size ranges							Intermediate			19mm-28mm larval size ranges									
Section	9mm	10mm	11mm	12mm	13mm	14mm	15mm	16mm	17mm	18mm	19mm	20mm	21mm	22mm	23mm	24mm	25mm	26mm	27mm	28mm
A							1	2	1	3					1					
B							1	1	1	1	1		1	1	1		2	1		
C							3	2	4						1		1			
D							4	8	11	15	2	2	1	2	2	2	1	1		
	19mm-15mm larvae size range 11.00%							Int 61.00%			19mm-28mm larvae size range 28.00%									
Total %	0.00	0.00	0.00	0.00	0.00	0.00	11.11	16.04	20.98	23.45	3.70	2.46	2.46	3.70	6.17	2.46	4.93	2.46	0.00	0.00

Table 19. Diurnal Glow Worm larval size ranges found during May 2013

	9mm-15mm larval size ranges							Intermediate			19mm-28mm larval size ranges									
Section	9mm	10mm	11mm	12mm	13mm	14mm	15mm	16mm	17mm	18mm	19mm	20mm	21mm	22mm	23mm	24mm	25mm	26mm	27mm	28mm
A									1	1	1				1					
B							1	1	2	1		2		1			1			
C							3		1	1					2		1			
D							3	1	2	3	3	5	1	1			3	1		1
	19mm-15mm larvae size range 16.00%							Int 31.00%			19mm-28mm larvae size range 53.00%									
Total %	0.00	0.00	0.00	0.00	0.00	0.00	15.55	4.44	13.33	13.33	8.88	15.55	2.22	4.44	6.66	0.00	11.11	2.22	0.00	2.22

The real factor influencing the whole of the glowing season was the late Spring. Larval activity along sections A, B, C and D began as late as the second week of April, yet ended more or less on time around the third week of May.

A total of 103 larvae were found during our late afternoon or early evening surveys, which was considerably more than in 2012, yet the final total of females recorded in 2013 was 100 lower than in 2012.

2.6 Summary of diurnal Spring larval size data between 2009 and 2013

Table 20. Summary of Glow Worm larval size ranges found during April 2009 - 2013

	9mm-15mm larval size ranges							Intermediate			19mm-28mm larval size ranges									
Total %	0.00	0.00	0.00	0.00	0.00	0.00	1.81	5.45	1.81	7.27	1.81	7.27	5.45	16.36	20.00	10.90	10.90	9.09	1.81	0.00
Total %	0.00	0.00	0.00	0.00	1.14	1.14	14.94	14.94	5.74	8.04	9.19	10.34	4.59	3.44	4.59	8.04	10.34	2.29	1.14	1.14
Total %	0.00	0.00	0.00	0.00	1.61	0.53	8.60	9.67	10.21	11.29	9.13	17.74	6.98	6.98	4.83	2.68	5.37	0.53	1.61	0.00
Total %	0.00	0.00	0.00	0.00	2.56	2.56	10.25	2.56	12.82	10.25	15.38	5.12	10.25	7.69	5.12	7.69	2.56	0.00	7.69	0.00
Total %	0.00	0.00	0.00	0.00	0.00	0.00	11.11	16.45	21.51	22.78	3.79	2.53	2.53	3.79	5.06	2.53	5.06	2.53	0.00	0.00

Table 21. Summary of Glow Worm larval size percentage ranges during April 2009 - 2013

Total %	Larvae size range (9mm-15mm) 2.00%	Intermediate 11.00%	Larvae size range (19mm-28mm) 87.00%
Total %	Larvae size range (9mm-15mm) 16.00%	Intermediate 29.00%	Larvae size range (19mm-28mm) 55.00%
Total %	Larvae size range (9mm-15mm) 11.00%	Intermediate 31.00%	Larvae size range (19mm-28mm) 58.00%
Total %	Larvae size range (9mm-15mm) 15.00%	Intermediate 23.00%	Larvae size range (19mm-28mm) 62.00%
Total %	Larvae size range (9mm-15mm) 11.00%	Intermediate 61.00%	Larvae size range (19mm-28mm) 28.00%

Table 22. Average monthly larval size ranges recorded during Spring 2009 - 2013

	9mm-15mm larvae					19mm-28mm larvae				
	2009	2010	2011	2012	2013	2009	2010	2011	2012	2013
March			14.37mm					20.20mm	23.25mm	
April	15.00mm	14.92mm	14.65mm	14.50mm	15.00mm	23.13mm	22.42mm	21.04mm	22.00mm	22.60mm
May	14.00mm	15.00mm			15.00mm	23.08mm	23.81mm	23.75mm	22.00mm	22.04mm

Larvae recorded purely during diurnal surveys in Spring, have been found to measure between 13mm and 28mm, which are thought likely to be larvae in the pre-pupation stage.

Prolonged cold weather during late February, March and into April, clearly delays the resumption of post over-wintering activity, but we have found no real evidence to suggest that very cold weather during December and January, affects larvae the same way. The cold March of Spring 2013, seems to illustrate this by virtually double the percentage of intermediate, and half the percentage of larger larvae recorded in four previous years.

The average larval size of the Clipstone Old Quarter population, has decreased annually since 2009. This is probably due to periods of dry weather the previous late Summer and Autumn, ultimately causing larval dehydration, the inability to find food and then death.

3.0 Spring and Summer 2013 nocturnal surveying reports

Diurnal surveying of Glow Worm larvae has been ongoing at Clipstone Old Quarter for several years, but we had never surveyed nocturnally for larvae in Spring before. We had always recorded any larvae found, or larval bioluminescence produced during our surveys for adults, but had found that no (or at least very little) larval bioluminescence was very much in evidence before mid-July.

Study into larval bioluminescence produced by both wild and captive larvae began back in Autumn 2012 and it was noted at the time, that most bioluminescence ceased around the time of the Autumnal equinox in September. Wondering if larval bioluminescence might recommence again at around the time of the Spring Equinox in the middle of March, was one question to try and answer in Spring 2013.

So a series of evening site visits began as early as the first week of January, to look for larval bioluminescence. Visits took place when the temperature was thought mild enough for larval activity. We determined in Project 2: Phase 1. 2012, that larval activity was best expected when the temperature was around 8ºC or above.

Six nocturnal surveys during January produced nothing and no surveys were conducted in February or March, as the temperature consistently remained below 8ºC.

All was going well, until a prolonged cold February and March effectively stopped any chance of us recording larval bioluminescence around the time of the Spring Equinox.

Eight surveys in the second half of April again produced nothing, even though larvae were known to have become active from April 11th. 23 surveys were carried out during May and after more blank nights, larval bioluminescence was unexpectedly noted on May 10th, and then on an additional three more evenings ending on May 21st. Bioluminescence exhibited by all but three of the 24 larvae recorded during May, came from fully fed, pre-pupating larvae. A summary of the recorded bioluminescence is given below.

10/05/13. Six larvae found, all found between 23:10h and 00:00h. All glows single, from darkest areas of section J and of long duration (10+sec) One pupating male larva found glowing, eventually pupated on 16/05/13. Lowest T2 temperature recorded at 10°C.

12/05/13. Seven larvae found. Two larvae found within minutes between 22:50h and 23:00h, then five found between 23:50h and 00:30h. All glows single, from darkest areas of section J and of long duration (10+sec). Lowest T2 temperature recorded at 10°C.

15/05/13. Four larvae found. All producing single, long duration glows between 23:00h and 00:55h, with a temperature ranging from 5°C - 4°C at T2.

21/05/13. Seven larvae found. Some producing single, long duration glows, but three larvae produced several shorter glows before being measured. All larvae were found between 22:48h and 00:03h. Temperature of 11°C at T2.

One larva found glowing on the edge of a forest track on May 10th, was clearly in the early stages of pupation, even though it was in a completely open situation, covered only by a blade of grass. It eventually pupated on May 16th, before emerging on May 27th. On May 30th, a bright glow was found to be emanating from a freshly formed (still cream coloured) female pupa, tucked down the side of a loose stone. The location of this pupa was marked, the pupa left on site and monitored every other evening, but was found largely eaten, two or three days before

expected emergence. It was believed to have been predated by other invertebrates.

3.1 Spring and Summer 2013 larval size data (nocturnal)

Table 23 shows how the average length of the larvae recorded, changes and becomes smaller for larvae in both larval size ranges. There was a remarkable similarity between the lengths of larvae found after dark and those found during daylight (see Table 17) in May.

Table 23. The average larval size ranges recorded nocturnally - May and June 2013

	9mm-15mm larval size ranges	Intermediate	19mm-28mm larval size ranges
May	15.00mm/1	17.00mm/10	21.92mm/13
June	11.76mm/13	17.00mm/2	19.00mm/1

Table 24. Nocturnal Glow Worm larval size ranges found during May 2013

	9mm-15mm larval size ranges							Intermediate			19mm-28mm larval size ranges									
Section	9mm	10mm	11mm	12mm	13mm	14mm	15mm	16mm	17mm	18mm	19mm	20mm	21mm	22mm	23mm	24mm	25mm	26mm	27mm	28mm
D																				
E																				
F																				
G																				
I																				
J								2	6	1	1	4	1	2	1	2	2			
K							1			1										
L																				
M																				
N																				
O																				
S																				
	9mm-15mm larvae size range 4.00%							Int 42.00%			19mm-28mm larvae size range 54.00%									
Total %	0.00	0.00	0.00	0.00	0.00	0.00	4.16	8.33	25.00	8.33	4.16	16.66	4.16	8.33	4.16	8.33	8.33	0.00	0.00	0.00

Table 25. Nocturnal Glow Worm larval size ranges found during June 2013

	9mm-15mm larval size ranges							Intermediate			19mm-28mm larval size ranges									
Section	9mm	10mm	11mm	12mm	13mm	14mm	15mm	16mm	17mm	18mm	19mm	20mm	21mm	22mm	23mm	24mm	25mm	26mm	27mm	28mm
D																				
E																				
F																				
G																				
I		1	2			1														
J						1														
K											1									
L																				
M		1	1			1		1												
N		1		1	1					1										
O					1															
S		1																		
	9mm-15mm larvae size range 82.00%							Int 12.00%			19mm-28mm larvae size range 6.00%									
Total %	0.00	25.00	18.75	6.25	12.50	18.75	0.00	6.25	0.00	6.25	6.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Tables 24 and 25 on the previous page, provide evidence of change-over in the bioluminescence produced by Glow Worm larvae at Clipstone Old Quarter in May and June 2013.

During May, long duration bioluminescence was produced largely by pre-pupating larvae. Bioluminescence during June became confined to the typical, regular short glows produced by hunting larvae, those with another year of development still to complete. The change in percentages of both smaller and larger larval size ranges is also striking.

3.2 Spring and Summer larval bioluminescence

Larval bioluminescence observed during May was interesting. With larval activity not commencing until early April, it was still five or six weeks before any bioluminescence was recorded from wild larvae. Even if larval activity had commenced as usual in early March, there would still have been no resumption of larval bioluminescence until well after the Spring Equinox anyway. Bioluminescence was even recorded when the ground temperature was as low as 4°C on one occasion and all larvae were found inactive and producing single long duration glows. Bioluminescence often lasted for much longer than a minute, with one larva recorded glowing continuously for over five minutes.

The 11 captive larvae being kept through the Winter (and at milder temperatures) by Martin Dale and ourselves as part of Project 2: Phase 1. 2012, exhibited bioluminescence so similar to that of wild larvae, that it is difficult to put down as being purely coincidental. Larva 1 for instance, glowed continuously for six minutes on February 20th, but was not observed glowing again until producing long duration bioluminescence on successive nights between May 13th and 17th, just prior to a final moult.

Regular bioluminescence associated with hunting larvae at Clipstone Old Quarter, finally resumed from June 21st.

4.0 Larval activity and bioluminescence during Autumn

Nationally and historically, little study seems to have been devoted to the activity of Glow Worm larvae after the end of the adult glowing season in early August. Certainly we had very little data ourselves, so even if just for our own reasons, we decided to make a concerted effort to expand our knowledge of larval activity during the Autumn. Project 2: Phase 1. 2012, was designed to run in conjunction with Project 1: Phase 1. 2012, which is looking more into larval bioluminescence. Despite having gained a great deal of knowledge about the glowing habits of female Glow Worms, we had very little knowledge of the post-adult season.

Some aspects we wanted to find more about were larval distribution in relation to forest paths and tracks, their typical hunting range and activity during the latter months of the year. These, coupled with certain aspects of larval bioluminescence and behaviour in the wild, compared to that exhibited by captive larvae, all go to form the basis for Project 1: Phase 1. 2012.

4.1 Autumn 2012 larval size data

Since 2009, we had size data for 30 larvae out of a total of 43 larvae found during the months June-August. So after the end of the adult glowing season in 2012, detailed research commenced. This section details and breaks down the available data recorded from Autumn 2012.

Table 26. The average larval size ranges recorded during Autumn 2012

	9mm-15mm larval size ranges	Intermediate	19mm-28mm larval size ranges
July	12.40mm/5	N/A	N/A
August	12.68mm/50	16.89mm/19	22.30mm/33
September	13.40mm/5	17.22mm/9	22.50mm/8
October	14.11mm/9	18.00mm/3	21.41mm/17
Spring Avg	14.63mm/52	16.69mm/115	22.46mm/321

Table 27. Glow Worm larval size ranges found during August 2012

	9mm-15mm larval size ranges							Intermediate			19mm-28mm larval size ranges									
Section	9mm	10mm	11mm	12mm	13mm	14mm	15mm	16mm	17mm	18mm	19mm	20mm	21mm	22mm	23mm	24mm	25mm	26mm	27mm	28mm
D			1		1		1	1												
E															1					
F				1						1	2									1
G					1		1													
I						1								1			2			
J		4	4	6	11	8	6	7	5	5	1	8	1	6	2	3	3	1		
K				1		1	1									1				
L	1																			
M																				
	9mm-15mm larval size ranges 49.0%							Int 18.0%			19mm-28mm larval size ranges 33.0%									
Total %	0.98	3.92	4.90	7.84	12.74	9.80	8.82	7.84	4.90	5.88	2.94	7.84	0.98	6.86	2.94	3.92	4.90	0.98	0.00	0.98

Table 28. Glow Worm larval size ranges found during September 2012

	9mm-15mm larval size ranges							Intermediate			19mm-28mm larval size ranges									
Section	9mm	10mm	11mm	12mm	13mm	14mm	15mm	16mm	17mm	18mm	19mm	20mm	21mm	22mm	23mm	24mm	25mm	26mm	27mm	28mm
D														1						
E																				
F																				
G																				
I							1							1						
J	1				1		1	2	3	2	1	1		1					1	
K							1													
L										2				1			1			
M																				
	9mm-15mm larval size ranges 23.0%							Int 41.0%			19mm-28mm larval size ranges 36.0%									
Total %	4.54	0.00	0.00	0.00	4.54	0.00	13.63	9.09	13.63	18.18	4.54	4.54	0.00	18.18	0.00	0.00	4.54	0.00	4.54	0.00

Table 29. Glow Worm larval size ranges found during October 2012

	9mm-15mm larval size ranges							Intermediate			19mm-28mm larval size ranges									
Section	9mm	10mm	11mm	12mm	13mm	14mm	15mm	16mm	17mm	18mm	19mm	20mm	21mm	22mm	23mm	24mm	25mm	26mm	27mm	28mm
D							1													
E																				
F											1									
G																				
I																				1
J					2	4	2			3	2	3	4	1	3	1				
K																				
L																				
M												1								
	9mm-15mm larval size ranges 31.0%							Int 10.5%			19mm-28mm larval size ranges 58.5%									
Total %	0.00	0.00	0.00	0.00	6.89	13.79	10.34	0.00	0.00	10.34	10.34	13.79	13.79	3.44	10.34	3.44	0.00	0.00	0.00	3.44

The above table does not include a 7mm long larvae recorded on 24/10/12.

By the end of December 2012, we had accumulated larval size and age ratio data for 154 larvae out of a total of 180 found on 35 evenings/nights. This at least provides us with a baseline for further research. After several

evening surveys, we realised that most larvae fell quite clearly into two distinct groups based on size. When we published our initial findings last year, these groups were based on larval size ranges of 9-15mm and 19-28mm, which were (incorrectly) referred to as 1st calendar and 2nd calendar year larvae. Larvae falling into a size range between the two main groups and were referred to as 'intermediate'.

4.2 Autumn 2013 larval size data

A total of 359 larvae were recorded during 43 nocturnal surveys out of a total of 81, from June 1st to October 23rd. From the total number of larvae, we managed to get size data for approximately 321 of these, so we were very pleased with the amount of useful data we obtained.

Greatest larval activity came on several nights during a ten day period running from the last week of August, till the end of the first week of September.

Table 30. The average larval sizes recorded nocturnally during 2013

	9mm-15mm larval size ranges	Intermediate	19mm-28mm larval size ranges
May	15.00mm/1	16.88mm/9	21.66mm/12
June	11.76mm/13	17.00mm/2	19.00mm/1
July	12.53mm/17	17.00mm/4	20.00mm/1
August	13.00mm/33	17.50mm/8	21.68mm/22
September	13.92mm/52	16.97mm/40	20.97mm/69
October	14.09mm/11	17.36mm/19	21.17mm/29
Spring Avg	15.00mm/16	17.20mm/63	22.25mm/47

Larval bioluminescence was noted more frequently and generally earlier than in 2012 and was clearly affected by the weather conditions.

Table 30 summarises the average larval lengths recorded by nocturnal surveying at Clipstone Old Quarter between May and October.

The shortening of larval lengths after the majority of larvae producing adults in 2013, had completed or begun the pupation process in May, has already been discussed in section 3.1.

Table 31. Nocturnal Glow Worm larval size ranges found during July 2013

	9mm-15mm larval size ranges							Intermediate			19mm-28mm larval size ranges									
Section	9mm	10mm	11mm	12mm	13mm	14mm	15mm	16mm	17mm	18mm	19mm	20mm	21mm	22mm	23mm	24mm	25mm	26mm	27mm	28mm
D						1														
E					2	1	1													
F																				
G																				
I		1		2		1		1												
J				2		1		1	1											
K		1					1			1		1								
L																				
M				1																
N			1																	
O																				
S																				
	9mm-15mm larvae size range 76.00%							Int 19.00%			19mm-28mm larvae size range 5.00%									
Total %	0.00	9.52	4.76	23.80	9.52	19.04	9.52	9.52	4.76	4.76	0.00	4.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 32. Nocturnal Glow Worm larval size ranges found during August 2013

	9mm-15mm larval size ranges							Intermediate			19mm-28mm larval size ranges									
Section	9mm	10mm	11mm	12mm	13mm	14mm	15mm	16mm	17mm	18mm	19mm	20mm	21mm	22mm	23mm	24mm	25mm	26mm	27mm	28mm
D				2	1				1											
E				1	1	3			2				1							
F																				
G																				
I		2		3	3		2			3	1		1							
J		1	1		4	2	2			1	2	4	1	1			3			
K					1	1						2	1	2		1	1	1		
L						1	1													
M																				
N									1											
O																				
S					1															
	9mm-15mm larvae size range 52.00%							Int 13.00%			19mm-28mm larvae size range 35.00%									
Total %	0.00	4.76	1.58	9.52	17.46	11.11	7.93	0.00	6.34	6.34	4.76	9.52	6.34	4.76	0.00	1.58	6.34	1.58	0.00	0.00

Table 33. Nocturnal Glow Worm larval size ranges found during September 2013

	9mm-15mm larval size ranges							Intermediate			19mm-28mm larval size ranges									
Section	9mm	10mm	11mm	12mm	13mm	14mm	15mm	16mm	17mm	18mm	19mm	20mm	21mm	22mm	23mm	24mm	25mm	26mm	27mm	28mm
D						1				1					1					
E					1	2	4				1	1		1						
F								1		1			1							
G																				
I				2	5	7	6	7	4	3	4	6		1	3	1	1	1		
J					1	5	3	1	2	3	4	5	3							
K					1		1	1	3	2	2	8	2	1	3		1			
L					1	1			1	1		5	1		1			1		
M						1	5	3	2		1									
N										1		1								
O					1		1	1	1		1		1	1	2	2				
S	1		1	1						1		1								
	9mm-15mm larvae size range 33.00%							Int 25.00%			19mm-28mm larvae size range 42.00%									
Total %	0.62	0.00	0.62	1.88	6.28	10.69	12.57	8.80	8.17	8.17	8.17	16.98	5.03	2.51	6.28	1.88	1.25	1.25	0.00	0.00

Short summaries of the three nights producing the best larval counts are produced below. Higher than normal larval bioluminescence had been evident from August 26th and continued until early October. During that time the ground conditions changed from being tinder dry, with the first rain for many weeks coming on September 6th. Larval activity increased with the wetter conditions and a series of mild evenings and nights produced the most activity and highest numbers of larvae recorded during any of our nocturnal surveys.

26/08/13. A site record of 28 larvae were located in ten survey sections. Weather clear and mild, with the general ground conditions continuing to be very dry. Many larvae appeared very thin, with no signs of having fed recently.

06/09/13. A new site record count of 48 larvae, came after the first days rain for several weeks. There were signs that some larvae had finally either taken on water or had fed. A good number of larvae were located well off the ground, on plant stems etc.

23/09/15. The warm temperatures this evening produced a total of 29 larvae. Many were actively hunting and producing the characteristic short glows.

Table 34. Nocturnal Glow Worm larval size ranges found during October 2013

	9mm-15mm larval size ranges							Intermediate			19mm-28mm larval size ranges									
Section	9mm	10mm	11mm	12mm	13mm	14mm	15mm	16mm	17mm	18mm	19mm	20mm	21mm	22mm	23mm	24mm	25mm	26mm	27mm	28mm
D								1			1									
E									1		1		1							
F																				
G																				
I				1		3	1	1	1	4	1	1	2	1	1	1		1		
J						1	1		1	1	1	1	2	2			1			
K							2	1	1	2	2	1			1					
L										1		1		1						
M					1					3		2			1					
N																				
O						1		1					1							
S														1						
	9mm-15mm larvae size range 19.00%							Int 32.00%			19mm-28mm larvae size range 49.00%									
Total %	0.00	0.00	0.00	1.69	1.69	8.47	6.77	6.77	6.77	18.64	10.16	10.16	10.16	8.47	5.08	1.69	1.69	1.69	0.00	0.00

Table 35. Monthly larval size percentage found nocturnally during 2012 and 2013

	9mm-15mm size range		Intermediate		19mm-28mm size range	
	2012	2013	2012	2013	2012	2013
May		4.00%		42.00%		54.00%
June		82.00%		12.00%		6.00%
July		76.00%		19.00%		5.00%
August	49.00%	52.00%	18.00%	13.00%	33.00%	35.00%
September	23.00%	33.00%	41.00%	25.00%	36.00%	42.00%
October	31.00%	19.00%	10.00%	32.00%	59.00%	49.00%

4.3 On site larval distribution and hunting range

In 2012, we regularly surveyed nine sections of the study site, when the most profitable section for larvae proved to be section J. This forest track runs north to south on a gentle incline, protected from the worst of the elements by a belt of mature Pines. The sides of the track have gradually become banked after years of track levelling, following the Dukeries Car Rally held in June each year. Bracken and Grasses dominate the vegetation, and section J is in many ways, representative of many sections found on site.

Precisely why section J proved to be so productive for larvae, is now believed to be linked to the much longer period of time this section has been colonised by Glow Worms, producing a consistent number of females present on an annual basis.

Although section J was again productive in 2013, section I (which runs parallel to the upper part of J about 200m further west) proved to be even better. We located just seven larvae along section I in 2012, but recorded a total of 90 larvae from section I in 2013, which was staggeringly higher than the previous year.

Going on the number of female Glow Worms found in section I in 2012 (52f) and 2013 (12f), the number of larvae

found the following Autumn, seems to oppose the number of adults found in more recently populated sections.

Only through consistent surveying, have we been able to produce this map, which breaks the Clipstone Old Quarter colony into two main populations (GW1 and GW2) with smaller, more recent or possibly relic populations centred around GW1e, GW1i, GW1r, GW1m and GW1s.

Over a number of years, larval movement through hunting, or wandering to find suitable pupation sites (the only means of Glow Worm movement and possible colonisation of new areas) has allowed these populations to merge, giving the overall appearance of a large single colony spread over a wide area.

When the number of adults recorded near GW1e, GW1i, GW1r, GW1m and GW1s, is low during the glowing season, the number of larvae likely to be present in those sections the following Autumn will be higher. This is assuming that larval mortality rates are similar across the entire area and we have found no evidence to suggest otherwise.

In 2012 we thought that temperature along section J could be the key factor, as the upper reaches of both that and section I, mark the site's highest elevation point. The recorded temperature in this area (T2 on the map in section 1.6) is usually at least 1°C higher than the lowest sections of the site (T1).

But with section I producing many more larvae than section J in 2013 yet sharing the same ground and air temperature, it seems unlikely to us now, that temperature has any real influence over larval numbers, but the number of females present a year previously does. Over time, this annual fluctuation in larval numbers is likely to lessen through variations in larval development.

In 2013, we often extended our survey area to cover as many sections as possible, especially when larval activity was higher than average. We still avoided the grass sections of A, B and C and the difficult to survey section R. Larvae were found in most areas, but some sections proved to be disappointing in terms of larval numbers.

The heavily shaded sections of F and G, now seem to have become unsuitable for both the larvae and adult Glow Worms, with the number of adults declining greatly (especially in section F), over the past few years. For several weeks, we hardly recorded any larvae in the open sections of L and M, but eventually both these proved to be productive, especially once rain had fallen on September 6th, after a lengthy period of very dry weather.

Larvae in both years were found to hunt just off the forest tracks and paths, virtually always remaining within the vegetation boundary, or in the shade of small trees dotted along many sections. Individual larvae could often be found in the same area for several consecutive evenings, depending on the amount of vegetation present. Evidence suggested that hunting is largely confined to substrate under vegetation such as Bracken and Bramble, often within light grass and leaf litter etc along the Bracken line. Only a handful of larvae were recorded well away from vegetation, onto forest tracks or paths in both 2012 and 2013.

Larval over-wintering seems to take place well away from path edges, but more data is still required to confirm this.

4.4 Larval activity and bioluminescence

One of our original research intentions had been to determine the peak time for larval activity. Although being able to confirm that greatest larval activity occurred during late August and September, we have been unsuccessful in determining larval activity as being higher at any particular time of night. We can be confident though, that the evening following rain, will usually prove to be good for finding larvae.

Late Summer 2013 proved to be dry for several weeks and larval activity showed a tendency to decline. Many of the larvae located and measured at this time, were found to be extremely thin and suffering from severe dehydration. When rain did eventually fall on September 6th, we recorded an exceptionally high amount of larval activity and bioluminescence later the same evening, writing at the time that *"a new site record count of 48 larvae,*

came after the first day's rain for several weeks and there were signs that some larvae had finally either taken on water or had fed".

In September 2012, a general cessation of bioluminescent activity was found to coincide with a sudden drop in the GPN (glows per night) rates and larval bioluminescence shown by captive larvae as part of Project 1: Phase 1. 2012. Looking at the percentages of long duration glows recorded from wild larvae, the rate of larvae producing 10+ second bioluminescent glows suddenly rose from 7.14% (from a recorded total of 113 larvae) in August, to 37.03% (27 larvae) in September and then 21.21% (33 larvae) in October 2012.

Table 36. Long duration bioluminescent rates

	2012	nL	2013	nL
May	0.00%	0	83.33%	24
June	0.00%	2	0.00%	20
July	0.00%	5	0.00%	25
August	7.14%	113	9.45%	74
September	37.03%	27	16.94%	171
October	21.21%	33	17.39%	69

In 2013, the results obtained were 9.45% (from 74 larvae) in August, 16.94% (171 larvae) in September and 17.39% (69 larvae) in October 2013, but note the very large percentage of larvae producing long duration glows found in May.

So while larvae are clearly less inclined to glow from late Summer to early Autumn, the percentage of larvae producing long duration glows, shows a marked increase from September. This is assuming that the level of larval hunting activity remains the same across a population until late October or early November each year.

Our other research - Project 1: Phase 1. 2012 and Phase 2. 2013, were both devoted to recording larval bioluminescence, especially detecting any possible repeated patterns of activity. A substantial amount of data was gathered regarding bioluminescence exhibited by hunting/active larvae and clear patterns of peaks and troughs were found.

In captivity, two larvae were kept by ourselves during the latter part of 2012. These were kept in a naturally warm room at a constant temperature of 18 - 20°C, with nine larvae under the supervision of Martin Dale also in an unheated room, but one subject to greater temperature fluctuations of 12 - 17°C. Outdoor temperatures recorded from our study site, ranged from 6 - 17°C during evening surveys between August and November.

Despite the warmer temperatures larvae were generally kept at in captivity, the decline and eventual cessation of larval bioluminescence was in accordance with captive larvae kept at slightly lower temperatures by Martin Dale, and more importantly with larvae in the wild.

We assumed at the time, that the cessation of larval bioluminescence was more likely down to a change in day/night lengths. In 2012, this was found to occur around the time of equal day and night lengths, but this could not be confirmed in our 2013 research and this theory may now be unlikely.

4.5 Larval activity in relation to ground temperatures

Figures 06 and 07 show the larval counts and survey dates, against the temperature recorded at T2, only on dates when larvae were recorded during 2012 and 2013. Larval bioluminescence and activity clearly changed as the months progressed in both years and as the nights lengthened and as the average temperature dropped.

Female Glow Worms rarely glow if the temperature is below 8°C and the evening is damp but fine, but in 2012, they continued to glow during (and following) a torrential thunder storm. Heavy rain fails to stop glowing, if females have already lit up. In fact we have often found that rain can be indicative of a good site count.

Yet strangely, females can be almost completely absent on nights that would seem to provide the perfect conditions, almost as if the whole colony has had the night off. Large numbers of females being mated on the same night, would certainly seem to account for much of this absence, but a good number of females do reappear on the same night, following one, two or even three nights absence.

This near complete 'lights out' phenomenon has occurred here several times over the past four years study and there seems to be no obvious explanation for it. Adult or larval bioluminescence and the governing factors which influence it, must obviously be much more complicated than would be supposed.

Larval activity seems very much in accordance with that of adults. Although evening rain seems to deter larval activity, at least until after a lengthy period of dryness, rain early in the day seemed less likely to affect larval activity after dark. As long as the temperature held above 8°C, larval activity could be expected, but once the nights had lengthened, counts dropped off, no matter how mild it was.

Figure 06. 2012 larval counts and on site temperature

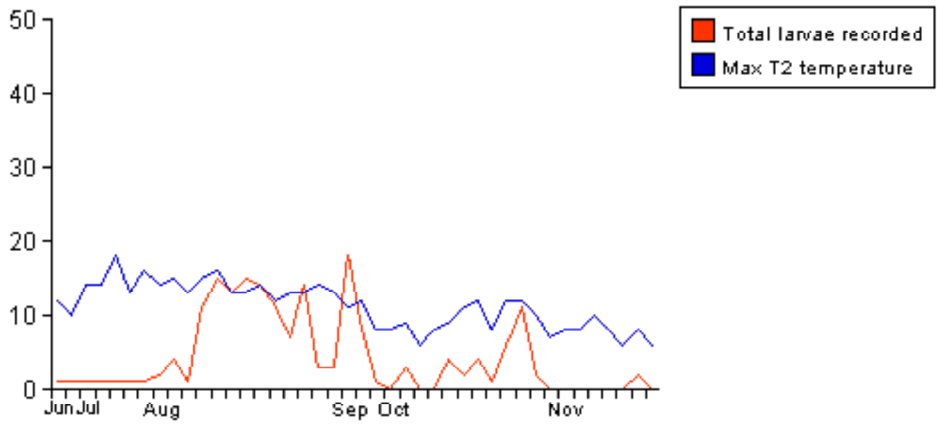
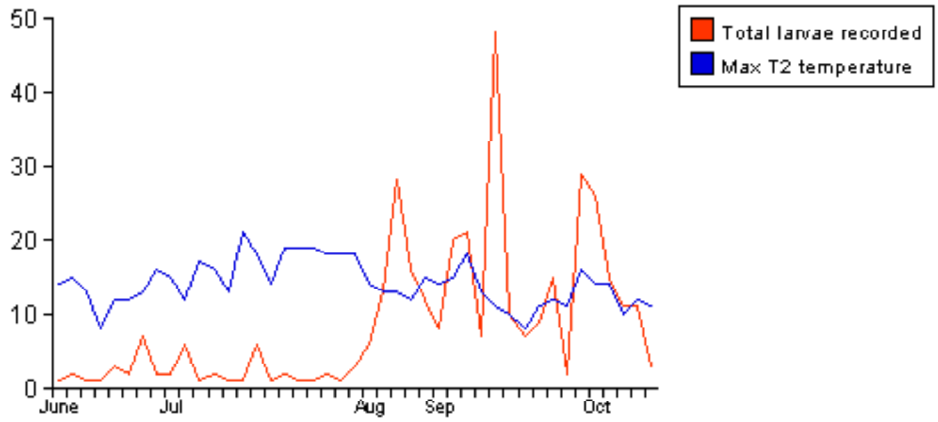


Figure 07. 2013 larval counts and on site temperature



We did have several cold overnight temperatures and slight grass frosts early in October 2012 and these lower temperatures seemed to end most larval bioluminescence or activity for a time. But a rise in temperature for field surveys in mid-October, did produce an increase in the number of larvae found. Many larvae recorded in October 2012, were located by long duration bioluminescent glows from stationary larvae, rather than short glows typical of active larvae found in August. Surveys on a run of relatively mild evenings when the temperature was above 8°C during the first half of November, proved negative until two were eventually located glowing within leaf litter on our sixth evening survey. The carpet of fallen leaves and dying/collapsing vegetation, made surveying extremely difficult.

The resulting data presented in Figures 06 and 07, shows considerable variation, with the two years producing extremely different results, probably due to the amount of rain in 2012 and the general lack of it in 2013. The high count of 48 larvae in early September 2013, marks the end of an extremely dry period, but does coincide with a rise in temperature at T2, as does the peak at the end of September.

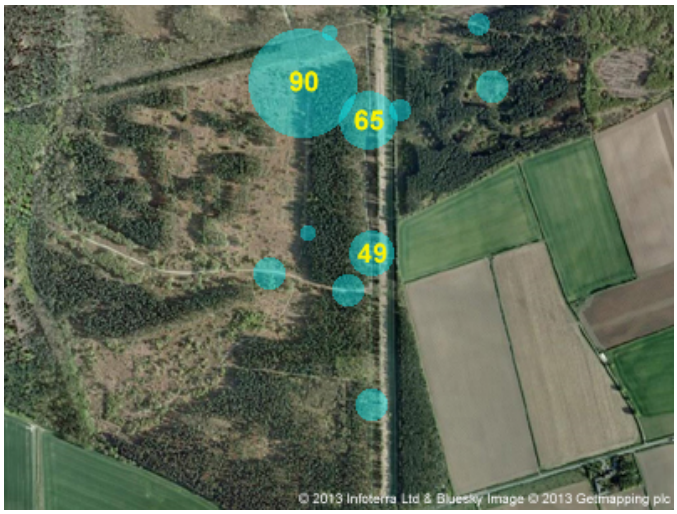
The overall warmer Summer of 2013, is evident from the temperatures and it is interesting to note that three small peaks in larval numbers during June and July, mirror three similar rises in temperature.

4.6 Larval population levels in 2012 and 2013

We have only used data obtained during August, September and October here. Using data from June and July only increases the possibility of counting the same larva twice or more over the five months, though this is very likely to have happened in both years.

Even allowing for some duplication, the results give a good representation of larval populations across the study site. The blue circles are centred within the middle of each of the sections surveyed in 2012 (upper right) and 2013 (lower right). The yellow numbers represent the highest number of larvae recorded.

Coverage was more extensive in 2013, as the number of larvae recorded proved to be significantly above the levels recorded in previous years. There are obvious differences between both years, with section J producing twice as many larvae in 2012 as it did in 2013 and note the dramatic increase in larvae present in section I.



4.7 Mortality rates within the larval population

It is generally believed that Glow Worm larvae have few, if any predators, as they are considered to be poisonous or at least taste unpleasant. But in order for a predator to discover and remember this, then they must surely have to attempt attack first?

Between August and October 2012, we recorded a total of nine instances where wild larvae were found glowing within approximately 1cm of other invertebrates. Bioluminescence from the (usually) stationary larvae, suggested that both parties had just come into immediate contact and that larval bioluminescence was clearly a responsive and/or a defensive reaction to the encounter.

Among the selection of invertebrates recorded, were two predatory species. The Wolf Spider *Pardosa amentata* was recorded with larvae on two occasions and the small Ground Beetle *Notiophilus biguttatus* once. Invertebrates offering no threat, but still appearing to initiate a bioluminescent reaction, were the Common Rough Woodlouse *Porcellio scaber*, Common Shiny Woodlouse *Oniscus asellus* and the Pill Millipede *Glomeris marginata*, which was recorded on four occasions with larvae.

But we believe larval mortality is as likely from human interference and dehydration, as it is through predation, especially at this site.

5.0 A short summary of our research results

So have we proved anything from such a large amount of data to date? Producing such an amount of data in quick succession as we have, often makes it difficult for the reader to take in. We have already discussed and updated our findings in earlier sections, but it is important to perhaps make the findings clear.

- **The number of active larvae present during the latter months of the year (post adult glowing season)** When the number of adults recorded from the more isolated (and smaller) populations, is low during the glowing season, the number of larvae present the following Autumn was found to be higher.

- **The period of larval activity during the Autumn and early Winter months** Larval activity continues well into October. Despite many site visits on mild Winter evenings/nights, we recorded no larvae between late November and February. The latest date we recorded larval bioluminescence was November 12th 2012. Both larvae were recorded glowing from deep within leaf litter and the bioluminescence was believed to be purely a reaction to predator approach, rather than hunting activity.

- **Larval bioluminescence during the year** Larval bioluminescence produced during hunting, was been found to be greatest during August and September and is often characterised by regular short glows, upwards of 4 seconds duration. Long duration bioluminescence increases during September and October, as larvae prepare for over-wintering. Larvae producing long duration bioluminescence, are often located motionless, on leaves and stems well off the ground. The trigger point/date for the cessation of larval bioluminescence in Autumn remains unknown. In 2012 this was around the time of the Autumn Equinox, but we found no evidence of this in our 2013 research. Despite being specifically looked for in Spring 2013, there was no resumption of bioluminescence at the time of the Spring Equinox, but extremely long duration glows were suddenly recorded between May 10th and 21st 2013, all by pre-pupating larvae.

- **Larval activity in early Spring** Larvae recorded diurnally (during daylight) in the early Spring, are found to be in the pre-pupation stage and moving into suitable open situations as preparation for the change into adult. Female Glow Worms emerging in shaded sites, will regularly move towards the nearest area of open sky in order to attract a mate. As such, the Glow Worm population at Clipstone Old Quarter is changing and heavily shaded sections such as F and G, are producing fewer females each year. This has taken place within the space of a few years. These small populations are also increasingly vulnerable to being eradicated by forestry operations and felling using heavy machinery.

- **Peak time for greatest larval activity** Although being able to confirm that the greatest level of larval activity occurs during late August and September, we have been unsuccessful in determining larval activity to being higher at any particular time of night.

- **The range of larval sizes present on site** For much of the year, this will be between 4mm and 28mm, although larvae recorded purely during diurnal surveys in Spring, have been found to measure between 13mm and 28mm. Several very small larvae have been recorded glowing late in the year.

- **The usual hunting range of larvae in relation to forest paths and tracks** Larvae in both years were found to hunt just off the forest tracks and paths, virtually always remaining within the vegetation boundary, or in the shade of small trees dotted along many sections. Individual larvae could often be found in the same area for several consecutive evenings, depending on the amount of vegetation present. Evidence suggests that hunting is largely confined to substrate under vegetation such as Bracken and Bramble, often within light grass and leaf litter etc along the Bracken line. In Autumn, only a handful of larvae were recorded on forest tracks or paths in both 2012 and 2013. Larval over-wintering seems to take place well away from path edges, possibly just behind the tree line.

- **Activity of larvae in relation to ground temperature** There is an increase in larval activity, both hunting and bioluminescence, when the evening/night temperature rises significantly. Prolonged periods of very dry conditions are detrimental to larvae, causing severe dehydration and likely death. Following the first rain, there can be a dramatic increase in larval activity and bioluminescence.

Please quote the following when referencing this document:
Pendleton, T.A. Pendleton, D.T. and Dale, M. "The size variation and age ratios found within the larval population of the Glow Worm (*Lampyris noctiluca*) during Autumn Project 2: Phase 2. 2013" www.eakringbirds.com; Feb 2014.