Colour morphs of the Ghost Moth *Hepialus humuli* L. (Lepidoptera, Hepialidae) in the Faroe Islands

Janus Hansen & Jens-Kjeld Jensen

Hansen, J. & J.-K. Jensen: Colour morphs of the Ghost Moth *Hepialus humuli* L. (Lepidoptera, Hepialidae) in the Faroe Islands.
Ent. Meddr 73: 123-130. Copenhagen, Denmark, 2005. ISSN 0013-8851.

Over a period of 10 years, 2,435 male Ghost Moths *Hepialus humuli thulensis* from the Faroe Islands were captured for a study of male colour morphs. The pattern of local variation found in the Faroe Islands supports the hypothesis that cryptic colouration is an adaptation to predation pressure from birds.

Janus Hansen, The Faroese Museum of Natural History, FO-100 Tórshavn, Faroe Islands.
Jens-Kjeld Jensen, FO-270 Nólsoy, Faroe Islands.

Introduction

The Ghost Moth *Hepialus humuli* L. is a common species widely distributed throughout Europe (Karsholt & Razowski, 1996). The Hepialidae is a primitive family of Lepidoptera. In mainland Europe the male upper wing has a bright glossy white colour, while the female is of a less conspicuous yellow to brown colour. The female wingspan (60-75 mm) is larger than that of males (45-60 mm) as is common in the Lepidoptera. The male's hind legs are set with large bushy hairs (fig. 1), from which a pheromone can be excreted that attracts females by a smell similar to that of Wild Carrot (*Daucus carota* L.) (Hoffmeyer, 1974; Skinner, 1984). At twilight, the pale male Ghost Moths will hover over the grass to attract females. After having mated, the female will fly over the grass and simply drop the eggs to the ground (Langer, 1957). The name Ghost Moth refers to this distinctive behaviour. In the Faroese language the moths are known as 'Hulda', which refers to mythological creatures that usually remain unseen.

Many Lepidoptera in the Shetland Islands are known to vary from the UK mainland forms, and are almost always darker (Ford, 1976). In the Ghost Moth subspecies of the Shetlands and Faroe Islands *H. h. thulensis* Newman, the male varies in colour from bright white to dark grey (Cockayne, 1955; Dahl, 1954; Skinner, 1984; Johnston, 1999) (fig. 2). *H .h. thulensis* is not known to occur in the Orkney Islands (Ford, 1976). According to Wolff (1970) the Faroe Ghost Moths could be classified as a separate subspecies *H. h. faeroensis* Dahl, however, *thulensis* is generally accepted.

In the Faroe Islands Jensen (1996) noted an apparent heterogeneous distribution of different colour morphs, and suggested an association with bird predation. Predation of Lepidoptera by birds has been summarised by Braby (1994) and he concluded that capture rates seemed rather low. However, the bird species he describes catching butterflies are mostly small passerines. Dahl (1954) describes a flock of terns in Eiði, Eysturoy, preying on Ghost Moths. He also collected anecdotal information that this is a common occurrence and indicated that this might have influence on the colouration of the moths. Furthermore he separated 62 collected male Ghost Moths into six colour morphs.

Fig. 1. Hind legs of male (top) and female (bottom) Faroese Ghost Moths.

When catching moths for this study we observed that terns and gulls started hunting the moths as soon as they made their appearance in the twilight. Ford (1976) notes that it has been shown that some birds specifically hunt for certain forms of moths, and claims that this is the reason for some very common species to be variable.

We hypothesize that colour polymorphism in male Ghost Moths is subject to two opposing selective forces. One is predation by birds resulting in a more cryptic colouration, the other is sexual selection in mate attraction causing a more conspicuous coloration advertising presence.

Material and Methods

The material for this study comprises 2,435 male Ghost Moths from the Faroe Islands captured in the period from 1993 to 2003. The majority of the moths was caught with hand-held butterfly nets of approximately 40 cm in diameter. Most were caught between 15 June and 20 July with much help from local people. Sampling was conducted during dusk in grasslands on many different locations (table 1; fig. 3). Only the moths from Mykines, and part of the moths on Nólsoy (163) were captured using a 250 W Mercury Vapour light-trap.

Figure 2. Colour morphs of male Faroese Ghost Moths *H. h. thulensis.* From top to bottom: LL, L, LD, D, DD.

The moths were usually sexed visually while sampling and the females were released again. Sexing was primarily by size of the large bushy hairs on the male hind legs (fig. 1). Colouration of the sexes can be very similar and is not 100% reliable. Furthermore the colouration of females can also be quite variable (fig. 4).

The sampled males were killed by freezing or with 25% ammonia, after which they were pinned and dried. Then they were identified and sexed once more by their bushy back legs, and as soon as they were dried, before any discolouration, they were classified to one of the following five colour morphs: LL (double light), L (light), LD (intermediate), D (dark) and DD (double dark). Colour morphs are illustrated in fig. 2 and were inspired by Jensen (1996) and Van Franeker and Wattel (1982).

The Ghost Moth material from this study has been deposited in the collection of the Museum of Natural History, Tórshavn, Faroe Islands.

Potential differences in capture rates of different morphs by light traps or by hand were evaluated by a Chi-squared test of association using 163 light-trapped and 114 hand-caught moths caught during June and July in 2001 on Nólsoy.

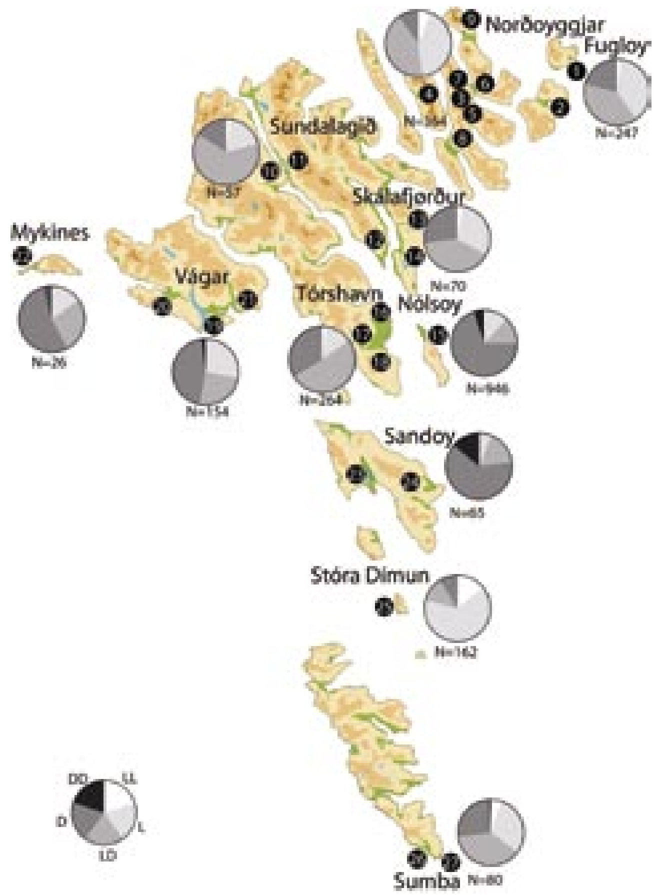

Fig. 3. Ratio of Ghost Moth morphs in each area, including both light-trapped and hand-netted moths. The numbers correspond to localities listed in table 1.

Locations close to each other were grouped to the same area, with up to 7 locations per area (table 1; fig. 3).

A brief overview of potential predatory birds closest to the moth sampling location was assembled. Birds considered to be predatory, based on our own observations and anecdotal evidence from Dahl (1954) are primarily Arctic Tern *Sterna paradisaea*, but also species such as Common Gull *Larus canus*, Black-headed Gull *Larus ridibundus*, Herring Gull *Larus argentatus* and Lesser Black-backed Gull *Larus fuscus*. Predation was classified as 'high' when birds from nearby colonies were known to hunt at or close by the Ghost Moth sampling location. Where no predation was known to occur, the predation was classified as 'low'. A Chi-squared test of association was conducted between colour morphs and predation level. Locations with no bird predation data (table 1) were excluded from this analysis.

Statistical tests of whether the colour of the Ghost Moths varied within or between years were not conducted, but bar charts are available (figs 5 and 6).

Fig. 4. Two female Faroese Ghost Moths.

Results

There was a highly significant difference in colour morphs of moths captured by the net-sampling method and the light-trap method at the same location and during the same period (Nólsoy, June-July 2001; χ^2=10.468; df=4; N=277; p<0.05), with higher abundance of darker morphs among the moths caught by nets (table 1). Further analyses were therefore restricted to our large samples of netted moths and we excluded the light-trapped moths from Mykines and Nólsoy.

With all locations pooled there was a highly significant difference in the ratio of colour morphs between 'high' and 'low' bird predation samples (χ^2=93; df=4; N=1788; p<0.001) (fig. 7). If there are geographical variations due to factors other than bird predation, then different sample sizes could influence this result.

There was no discernible pattern in the variation of the morph ratio between years (fig. 5). However, there appeared to be a trend of diminishing bright morphs from week 26 to 29 and rising again in week 30 (fig. 6).

Discussion

Overall the DD (darkest) and LL (lightest) morphs are found in the Faroe Islands in a similar proportion of the population. The LL form is more widespread, but this is not visible in overall numbers because at some locations, most notably in the Sandoy area, there are some relatively high frequencies of DD. Remarkably the LL and DD morphs hardly ever occur in the same area, local populations ranging either from LL to D or from L to DD. The most prevalent overall morph was the D type, which accounts for 41% of all caught individuals but varies in abundance between 9% to 67% depending on the area (fig. 3).

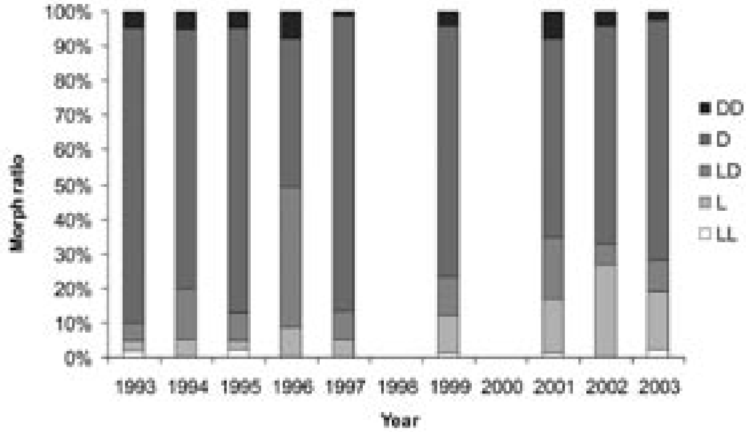

Fig. 5. Morph ratios of nine years of sampling, summed pr. year from Nólsoy.

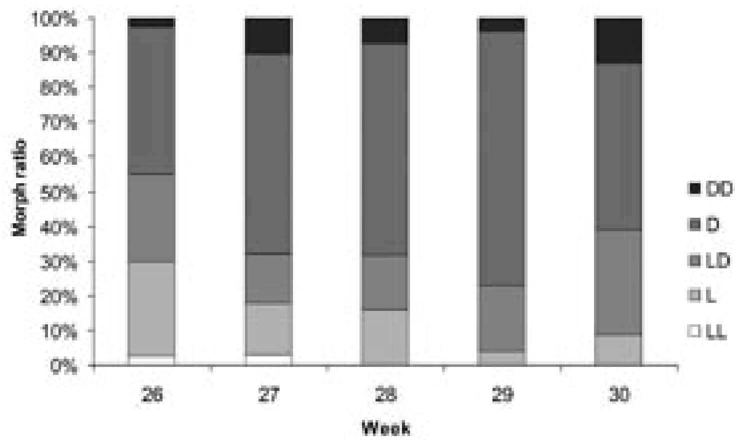

Fig. 6. Morph ratios of five weeks of sampling in Nólsoy in 2001.

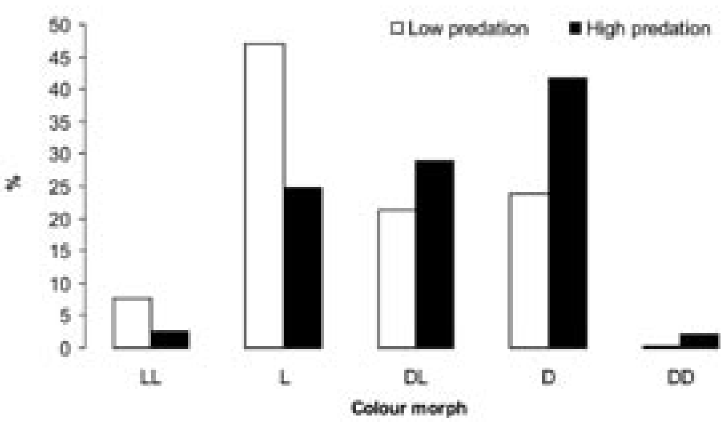

Fig. 7. The effects of high and low predation by birds on colour morphs of Ghost Moths in the Faroe Islands.

Table 1. Number of Ghost Moths and morphs caught and degree of predation in the respective locations. The numbers for 'Nólsoy a' and 'Mykines' are light-trapping data, which are excluded from certain analysis (see text). Data used to test light-trapped against hand-caught morphs are 'Nólsoy a' (light-trapped) and 'Nólsoy b' (hand-caught).

Area	Location Nr.	Name		N	Morphs LL,L,LD,D,DD	Bird predation
Fugloy	1	Hattarvík		185	1, 85, 74, 25, 0	High
	2	Svínoy		62	5, 9, 22, 26, 0	No data
Norðuroyggjar	3	Depil		106	3, 54, 42, 7, 0	High
	4	Kunoy		14	1, 2, 5, 6, 0	No data
	5	Norðtoftir		55	4, 13, 22, 16, 0	High
	6	Hvannasund		128	11, 63, 54, 0, 0	High
	7	Fossanes		25	3, 6, 14, 2, 0	High
	8	Klaksvík		17	0, 7, 9, 1, 0	Low
	9	Viðareiði		19	0, 7, 7, 5, 0	High
Sundalagið	10	Nesvík		14	1, 3, 8, 2, 0	High
	11	Norðskála		43	0, 8, 28, 7, 0	High
Skálafjørður	12	Innan Glyvur		3	0, 0, 1, 2, 0	High
	13	Lamba		39	2, 15, 13, 9, 0	High
	14	Runavík		28	0, 6, 14, 8, 0	Low
Nólsoy	15	Nólsoy		668	8,74,83,476,28	High
			a	163	4,32,32,84,11	
			b	114	0,11,18,74,11	
Tórshavn	16	Hoyvík		79	2, 4, 41, 32, 0	High
	17	Tórshavn		14	0, 5, 7, 2, 0	No data
	18	Argir		171	2, 25, 88, 56, 0	No data
Vágar	19	Leitisvatn		8	0, 0 , 2, 5, 1	High
	20	Sørvágur		98	1, 24, 23, 49, 1	Low
	21	Sandavágur		48	0, 18, 14, 15, 1	High
Mykines	22	Mykines		26	0, 4, 7, 14, 1	No data
Sandoy	23	Sandur		26	0, 1, 7, 13, 5	No data
	24	Skálavík		39	0, 3, 4, 28, 4	No data
Stóra Dímun	25	Stóra Dímun		162	22, 106, 19, 15, 0	Low
Sumba	26	Sumba		62	2, 17, 26, 16, 1	High
	27	Akraberg		18	2, 7, 4, 5, 0	No data
Total				2,435		

When looking at the geographical distribution on the map (fig. 3), the northernmost areas, Fugloy, Norðuroyggjar, Sundalagið and Skálafjørður (and Sumba), show a fairly equal distribution of morph ratio distributed around LD. The more centred islands, Vágar, Nólsoy and Sandoy, appear to have a higher frequency of DD and D morphs than other areas. Stóra Dímun has a strikingly high frequency of L and LL morphs and has low bird predation.

If it is assumed that light trapping results in an unbiased ratio of colour morphs in samples, then hand catching is biased towards darker morphs, i.e. the dark individuals are more often hand caught, than the light. This is perhaps unexpected and does not appear to conform with the hypothesis that more conspicuous forms are caught more often by predators. If the hypothesis is true, and birds do take more of the brighter morphs, then this discrepancy in the ratio between hand-caught and those taken by birds, may be due to the different viewpoint of the two 'predators'. While most of the Ghost Moths caught by humans are seen from the same angle as the birds do, i.e. with the ground as background, several are seen with the sky as background. This may produce the observed bias.

The colour morph ratio differed between the areas examined. As we are looking at small populations and island situations, differences might be related to a founder-effect. However, considering the small distances between some of our areas, we consider founder effects to be an unlikely explanation for our observations. So we suggest that there are other mechanisms that drive the differentiation of colour morphs within a given area. There is a significant difference between locations with high bird predation and low bird predation, with respect to ratio of colour morphs (fig. 7). High predation pressure by birds is correlated with an increased proportion of dark morphs. This is in line with the hypothesis that birds would select the lighter morphs that are more conspicuous to them. Such a selection pressure from birds would reduce the proportion of lighter Ghost Moth in the population. In the absence of bird predation, and especially on smaller isolated locations (e.g. Stóra Dímun) one would expect that the selection pressure is on the male moths to be as conspicuous as possible for the females to see them.

It seems that the ratio of morphs varies considerably between the years (fig. 5), but without a discernible pattern. On the other hand there seems to be a pattern in the variation of morph ratio between the weeks (fig. 6). This requires further sampling and should be conducted while including other factors, which may influence the morph ratio, such as bird predation and weather conditions.

Acknowledgements

S. Andreasen, Dorete Bloch, Tóta Árnadóttir, Kinna úr Dímun, Esbern í Eyðansstovu, Annika Gulklett, Marita Gulklett, Bergur Olsen, Aksal Poulsen, Poul Poulsen, Fríðleif Lydersen, Petur Mortensen, Annleyg Patursson, Eyðbjørt Simonsen, Poul Johannes and Bodil Simonsen with family, Hans Eli Sivertsen, Alf Sørensen, Jákup Sørensen and Tinna Asaadare Tótudóttir all provided highly appreciated support during our study. Bernard Zonfrillo, Garth N. Foster and Jan A. van Franeker kindly provided comments on the manuscript, as did the two referees Svend Kaaber and Thomas Simonsen.

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