Acta Zoologica Academiae Scientiarum Hungaricae 48 (2), pp. 89–99, 2002

OBSERVATIONS ON THE OVIPOSITING STRATEGY OF GORTYNA BORELII PIERRET, 1837 (LEPIDOPTERA, NOCTUIDAE) IN A BRITISH POPULATION

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The main British population of *Gortyna borelii* occurs on the north Essex coast, on sites very close to sea level. During 1999, 2000 and 2001, ovipositing strategies of *G. borelii* were studied providing details of egg laying behaviour, preferred oviposition host plants, height of ova deposition and distance of the oviposition site from the nearest larval food plant (*Peucedanum officinale*). Six oviposition host plants were identified, five of which were grass species: 75% of the observations were on *Elytrigia atherica* and *Elytrigia repens* with the female depositing eggs between the grass inflorescence and the outer leaf sheath. Sites with the highest incidence of oviposting females were dominated by long, coarse grasses (>75% of ground cover mainly *Elytrigia* spp.) and a sparse distribution (<25% of ground cover) of *Peucedanum officinale.* Surface morphology, size and shape of ova were described using scanning electron microscopy. The results of the study are important in the conservation of the species in the United Kingdom.

Key words: behaviour, *Gortyna borelii*, habitat, moth, ova, oviposition, sea level rise

INTRODUCTION

Fisher's Estuarine Moth *Gortyna borelii* PIERRET 1837 has a very limited distribution in the UK (HEATH & Emmet 1983, GIBSON 2000), restricted mainly to the Walton Backwaters area of north Essex in southeast England. The species has a widespread but localised European distribution and has been recorded in many countries in Central and Southern Europe (IPPOLITO & PARENZAN 1978, NOWACKI & FIBIGER 1996). *Gortyna borelii* is a large noctuid with a wingspan of 50–60 mm (IPPOLITO & PARENZAN 1978), and was first identified in Britain in 1968 (FISHER 1971). The sole larval food plant of the moth is *Peucedanum officinale* LINNEAUS, 1753 (Hog's fennel) in the United Kingdom, but it will feed on other species of *Peucedanum* in continental Europe (GYULAI 1987, DUMONT 1925–1926) and has been reared in captivity on other members of the Apiaceae (CHALMERS-HUNT 1972, GOATER 1973). In the United Kingdom, *Peucedanum officinale* is a plant of coastal grassland and its distribution is limited to two main localities: the north Essex coast around the Walton Backwaters area and the north

Kent coast between Faversham and Reculver (RANDALL & THORNTON 1996, WIGGINGTON 1999). *Gortyna borelii* is listed as Category 2 (Vulnerable) (SHIRT 1987) in the British Red Data Book, and is protected under Schedule 5 of the Wildlife and Countryside Act 1981 (GIBSON 2000). *Peucedanum officinale* is also included within the British Red Data Book as Lower Risk (near threatened) (WIGGINGTON 1999).

The majority of the British population of *G. borelii* occurs on coastal grassland, at <2 m above mean sea level. In continental Europe, however, the species is found within a diversity of habitats (GYULAI 1987, BUSCHMANN 1998–1999, STEINER 1998, KÖNIG 1959) and to altitudes of 1000 m (GYULAI 1987). In the United Kingdom, the habitat of *G. borelii* is particularly vulnerable to inundation by the sea as a result of rising sea levels. Sea levels are predicted to rise around the coasts of Britain by about 5 cm per decade as a result of climate change (CLIMATE CHANGE IMPACT REVIEW GROUP 1996). PETHICK (1993) also suggests that tectonic subsidence is accounting for a further relative sea level rise of 4–5 mm per year on the coast of Essex. The extinction of a *G. borelii* population in a river area (Necker Valley) in Germany is thought to be a result of prolonged flooding (STEINER 1985). To secure the long-term future of *G. borelii* in Britain it has been proposed to establish colonies further inland (GIBSON 2000), away from the dangers of sea level rise. There are, however, still many aspects of the life history and habitat requirements of this species that need to be understood before new colonies can be established. One of the most fundamental aspects is to determine the oviposition requirements and preferences of the species.

The flight period of *G. borelii* occurs from the beginning of September to the end of October and the moth diapauses in the egg stage, hatching the following spring (mid April to early May) – a period of 7 to 8 months (KÖNIG 1959). *Gortyna borelii* has been recorded ovipositing on dead grass stems in the UK (PLATTS 1981) and in Germany (STEINER 1998). However, the species of grass on which ovipositing was observed, the actual location of eggs on the plant or details of the process of oviposition were not, however, recorded by these authors. Other species of the same genus, *Gortyna flavago* DENIS et SCHIFFERMÜLLER, 1775 and *G. xanthenes* GERMAR, 1844, lay their eggs directly onto the larval food plant (IPPOLITO & PARENZAN 1978). *Gortyna borelii* has also been observed ovipositing directly onto its larval food plant (STEINER 1998, LÁSZLÓ RONKAY pers. comm.). The closely related species *Hydraecia immanis* GUENÉE, 1852 and *Hydraecia micacea* ESPER, 1789 are known to lay their eggs between the stem and outer leaf sheath of various grass species (FRENCH *et al.* 1973, DEEDAT *et al.* 1983, GIEBANK *et al.* 1984, LEVINE 1986).

RENWICK and CHEW (1994) suggest that oviposition behaviour and host acceptance in Lepidoptera can be reliant on a number of sensory cues, such as colour, texture, shape, and chemical stimulants. Furthermore, if the species lays eggs on plants, they generally have a preference for laying at a certain height (HINTON 1981). Also, factors such as temperature, relative humidity, wind and the time of the day are important for oviposition in many insects.

In previous papers, RINGWOOD *et al.* (2000, 2002) and HILL *et al.* (2002) have examined habitat characteristics of *G. borelii* and its larval food plant (*P. officinale*) in the United Kingdom and Germany. The objectives of the studies reported in this paper were to determine the preferred host plants for oviposition, the environmental requirements for ovipositing and the behaviour of *G. borelii* before, during and after oviposition. The studies also investigated the position of oviposition on preferred host plants and the distance of ovipositing from the nearest larval food plant. The results are discussed in terms of the conservation and management of the *G. borelii* population in the United Kingdom.

MATERIALS AND METHODS

The study was performed in 1999, 2000 and 2001 within the Walton Backwaters area of north Essex, UK. The area of study was approximately 95 hectares of coastal grassland, saltmarsh and scrub (*Prunus spinosa*). Stands of *Peucedanum officinale* grow in the coastal grassland between saltmarsh and scrub. Soil conditions and management of sites are reported in RINGWOOD *et al.* (2002).

To determine the incidence and location of oviposition in relation to habitat and vegetational structure, a transect route was set out in the area of study. The transect route incorporated all the main stands of *P. officinale* and other habitats found within the study area. The transect was divided into eleven sections of differing vegetational structure, habitat or density of *P. officinale*. A vegetation survey was carried out in each of these sections using a visual estimation of cover for each of the species present (BULLOCK 1996). The transect was walked twice a week during the flight period (beginning of September to end of October). At the start and finish of each transect survey details of the weather conditions, including air temperature, wind speed and cloud cover, were recorded. The transect was walked between 19:00 and 03:00 hours, and filtered torchlight (white light) was used to sight *G. borelii*. When ovipositing was observed, the plant species on which the moth was depositing her eggs, the height (cm) from ground, the distance from the nearest larval food plant (cm), the time of the observation and the transect section were recorded. Selectivity of host plant for ovipositing was assessed by χ^2 of observed and expected ovipositing events calculated from the incidence of potential host species for egg laying.

Behavioural observations were to evaluate the sequence of events preceding, during and subsequent to oviposition and also the length of ovipositing bouts. These observations were made twice a week during the flight period. Each behavioural observation period was approximately 2 hours in duration and performed between 19:00 and 06:00 hours. The behaviour was observed using filtered (white light) torchlight. At the start and end of each period, details of the weather conditions were recorded. The behavioural observation periods involved recording the time at the start and finish of each bout of each behaviour observed (i.e. the duration of each period of resting, crawling, ovipositing, flying, grooming and wing movement). If a female was observed ovipositing the same details (*i.e.* plant species, height) as those recorded during the transect surveys were noted.

Scanning electron microscopy of a sample of *G. borelii* eggs, collected under licence from English Nature, was used to determine their size, morphology and surface texture. The eggs were prepared without fixation by sputter coating with gold in a Nanotech Semprep2. They were then scanned using a Hitachi S430 scanning electron microscope.

RESULTS

Eighty-four observations of ovipositing were made over the three years of monitoring; fifty-five during transect surveys and twenty-nine during the behavioural observation sessions. The species of plant on which *G. borelii* was observed laying eggs are shown in Fig. 1. Six oviposition host plants were recorded, five of which were grass species: *Elytrigia atherica*, *E. repens*, *Arrhenatherum elatius*, *Dactylis glomerata* and *Holcus lanatus*. Two oviposition observations were made on *P. officinale*, the larval food plant. The most frequently observed host plant for oviposition was *E. atherica*, with 52% of the total observations and *Elytrigia* spp. made up 75% of the observations. The majority (73%) of oviposition behaviour was made on dead inflorescences and pseudostems of grasses. *Gortyna borelii* showed strong selectivity in its host plant for ovipositing. There was an under representation of ovipositing on *Festuca rubra* and *P. officinale* in relation to the dis-

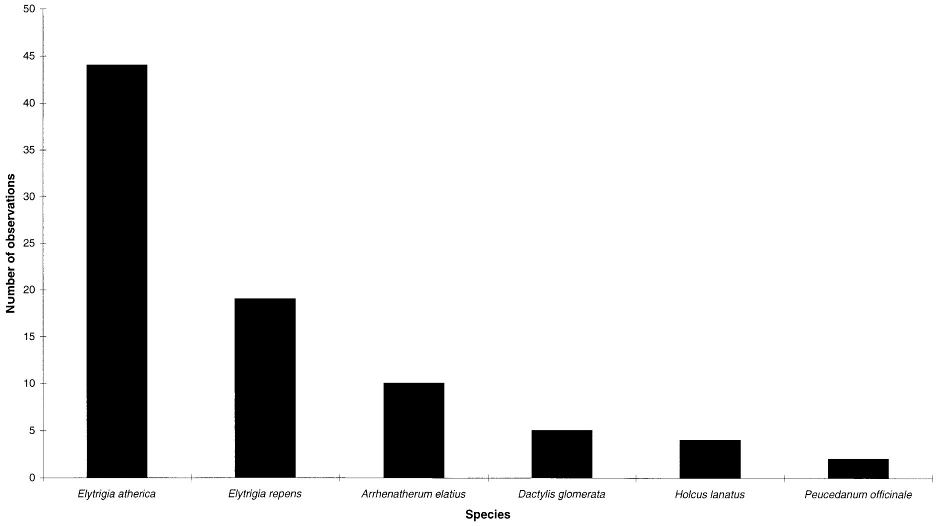


Fig. 1. The species on which *Gortyna borelii* was observed ovipositing

tribution of the two species of plant. Positive selectivity in ovipositing was observed for *Elytrigia* and *Arrhenatherum* as the incidence of ovipositing on these species was significantly greater than that expected (χ^2 (6 d.f) 61.3; P<0.001).

The requirements of *G. borelii* for a suitable species of grass for oviposition can be related to the vegetational structure of the areas where the most oviposition observations were made. The distribution of ovipositing was most frequent (66% of observations) in relatively sparse densities of *P. officinale* (<25% ground cover) with dense (>75%) ground cover of long, coarse grasses, characterised by *Elytrigia* spp. No oviposition observations were made within areas of scrub, saltmarsh, or grassland areas that supported a dense stand (>75% ground cover) of *P. officinale*.

Behavioural observations found that the female laid the eggs by probing with her ovipositor beneath the outer leaf sheath of the grass and depositing the eggs in a number of rows between the stem and the outer leaf sheath (Fig. 3). The eggs laid on *P. officinale* were deposited within a crevice in the stem axil of the plant. The ova are covered in mucus and are stuck to each other as well as to the stem. Over two hundred eggs were observed being laid in one batch. A typical ovipositing behavioural observation session is represented in Fig. 2. The period immediately before ovipositing is characterised by crawling, wing movement and resting bouts. The majority of the behaviour bouts observed both preceding (71%) and subsequent (68%) to oviposition were crawling. When the female is crawling, probing of suitable sites for egg laying is observed, however, the cue for egg deposition is

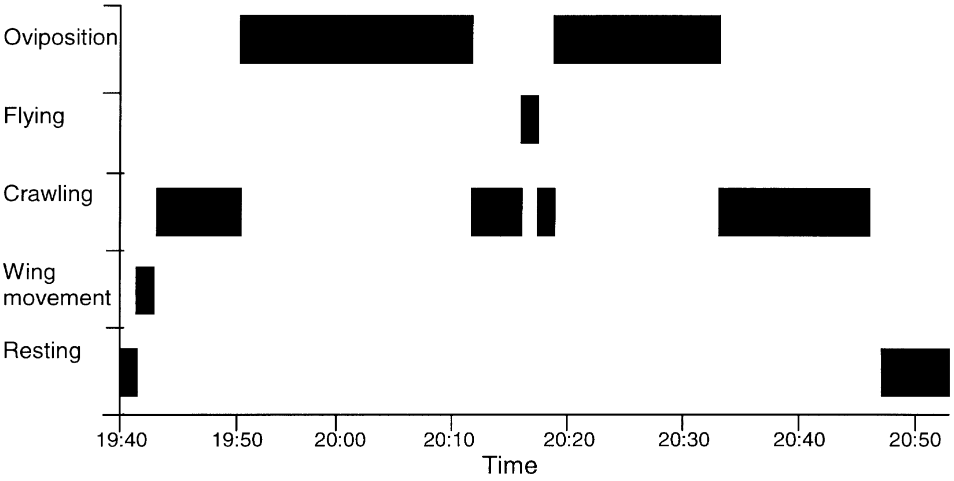


Fig. 2. Example ovipositing behavioural observation session

Table 1. Details of the oviposition characteristics of *Gortyna borelii*

	Mean±S. D.	Range
Air temperature during oviposition observations	14.1±1.8°C	10–18°C
Distance of ovipositing from the nearest food plant	30.0±29.6 cm	0–150 cm
Duration of oviposition bouts	15.6±11.7 mins	1–48 mins
Height at which oviposition was observed	43.8±13.5 cm	15–75 cm

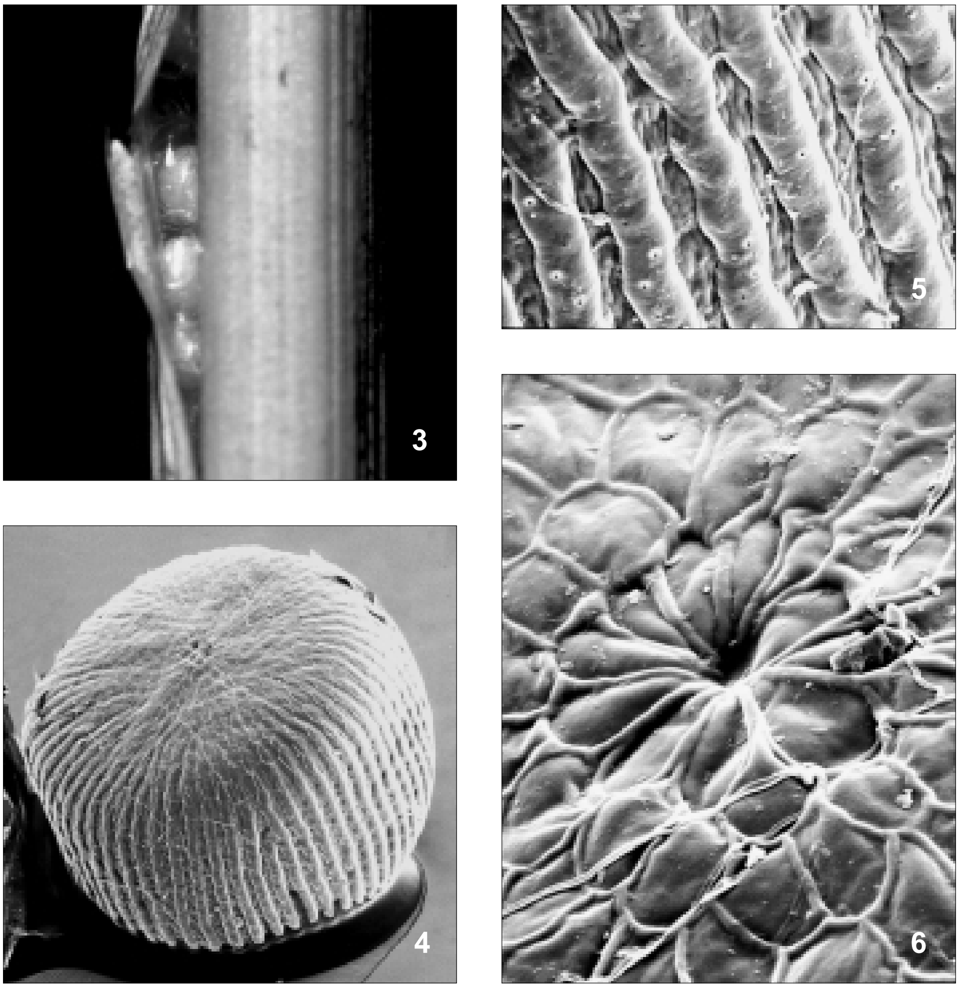
not clear from the data collected. The duration of oviposition bouts ranged from 1 minute to 48 minutes in length (Table 1).

The time period when oviposition was recorded most frequently was between 19:00 hrs and 22:00 hrs. It appears, however, that ovipositing could occur at anytime between dusk and dawn. Furthermore, the majority of egg laying observations were made when the air temperature was around 14°C and *Gortyna borelii* was not recorded egg laying when the temperature was below 10°C (Table 1). The weather conditions most favourable to oviposition appeared to be still (<2 on Beaufort Scale), overcast, humid and relatively mild. The preferred height for oviposition by *G. borelii* was observed to be between 40 and 45 cm from the ground surface (Table 1). The distance of ovipositing from the nearest larval food plant ranged from 0 cm to 150 cm (Table 1). However, the majority of observations were made within 30 cm of the closest food plant.

Ova ultrastructure was examined using scanning electron microscopy (Figs 4–6). Ova are spherical in shape with a flattened top and base and the sides have a ribbed surface structure. Flattened eggs are often characteristic of Lepidoptera that glue their eggs together (SCOBLE 1995). The ova are approximately 700 μm in diameter and 350 μm in height. The ribbed surface structures on the sides of ova are perforated by numerous aeropyles (2–3 μm in diameter). The ribs are approximately 10 μm in width. The rosette-like sculpture (Fig. 6) of the chorion that surrounds the micropylar area at the anterior pole of the egg is characteristic of many species of Lepidoptera (SCOBLE 1995). The micropyle is about 6 μm in diameter.

DISCUSSION

An understanding of the ovipositing strategy and requirements of *G. borelii* are important for the successful management and conservation of the UK population. The results from this study suggest that *G. borelii* has a preference for ovipositing on *E. atherica*, then *E. repens* and *A. elatius* (Fig. 1) and not its larval food plant (*P. officinale*). Consequently, *G. borelii* does not appear to be oviposition host specific. The preference for ovipositing on species of grass and not its larval food plant is similar to related species, for example *Hydraecia immanis* (GIEBANK *et al.* 1984, LEVINE 1986) and *H. micacea* (FRENCH *et al.* 1973). This strategy may provide an advantage to the moth as the stems of *P. officinale* do not provide a secure crevice within which the female can deposit her eggs. Any eggs laid onto *P.*



Figs 3–6. 3 = *Gortyna borelii* ova beneath the outer leaf sheath of a grass stem (Photo credit: MICKY ANDREWS). 4–6 = Scanning electron microscopy of *G. borelii* ovum (Photo credit: ZOE RINGWOOD): 4 = 700 µm diameter, 350 µm height; 5 = ribbed surface structure on the side of the ovum (ribs 10 µm in width, aeropyles 2–3 µm in diameter); 6 = micropylar area of the ovum (micropyle 6 µm in diameter)

officinale will therefore be exposed to the risks of predation and harsh winter weather conditions. This differs from the oviposition preferences of *G. xanthenes* and *G. flavago,* both species that lay eggs on their larval food plant (IPPOLITO & PARENZAN 1978). Consequently, the ovipositing characteristics of *G. borelii* in the United Kingdom appear to share more similarities with *Hydraecia* spp. than with species of *Gortyna*. However, where *G. borelii* occurs in forest steppe habitats in Hungary, the stems of the larval food plant appear to be the favoured oviposition site (LÁSZLÓ RONKAY pers. comm.). It is probable, as *G. borelii* occurs within a diversity of habitats across central and southern Europe, that the oviposition requirements of the species will differ from site to site.

Behavioural observations of *G. borelii* ovipositing followed a sequence of searching (crawling), surface texture evaluation (probing with the ovipositor) and finally acceptance by probing into an appropriate crevice (generally between the stem and outer leaf sheath of a blade of grass) and depositing the eggs. The host plants for ovipositing all, with one exception, have a relatively glabrous stem surface texture, the exception being *Holcus lanatus*. The dried grass stems chosen by *G. borelii* for oviposition are generally more resistant to decay during the winter, thus providing a secure niche for ova. All species of grass on which *G. borelii* was observed ovipositing, possess a loose outer leaf sheath, an ideal site for oviposition (a similar observation is noted with *Hydraecia immanis* (LEVINE 1986)).

As the preferred oviposition host for *G. borelii* is not the larval food plant in the United Kingdom, it could be suggested that the critical phase of the life cycle is the ability of freshly emerged larvae to migrate from over-wintering sites to the food plant. STEINER (1998) recorded *G. borelii* egg laying, in Germany, on grass stems up to 5 m away from the closest host plant. However, in the United Kingdom, distances of greater than 1.5 m have not been recorded, which may be due to the differences in environmental and vegetational conditions at sites in Germany and the UK (RINGWOOD *et al.* 2002). The ova are deposited in large batches, resulting in the likelihood that many neonate larvae will migrate to the same *P. officinale* plant to begin feeding. It is probable, however, that this migration accounts for a high level of mortality, with a substantial proportion of larvae being predated or not successfully locating a food plant. It is stated in HAGGETT (1981) that a maximum of just one pupa is found within each *P. officinale* rootstock, which suggests larvae either disperse a considerable distance from their hatching site or that a high level of mortality occurs during the larval stage.

The major requirement of the mated female is to recognise the most appropriate over-wintering habitat for the ova and the proximity of the habitat to the food plant. The density of the food plant and surrounding vegetation structure is therefore important in providing a suitable environment for ovipositing. The majority of

Table 2. The generalised phenology of *Gortyna borelii* and *Peucedanum officinal*e in the UK

G. borelii	Time of year	*P. officinale*	Time of year
Ova	mid September–late April	Senescence	early October–mid February
Larva	late April–early August	Stem growth	mid February–mid June
Pupa	early August–early September	Flowering	mid June–early September
Adult	early September–mid October	Seed dispersal	early September–mid October

observations of ovipositing were in areas with a relatively low density of *P. officinale* and a high density of *Elytrigia* spp. There seems to be a clear selectivity for ovipositing on *Elytrigia* spp and *Arrhenatherum* and an under representation on *Festuca* and *Peucedanum*. The reasons for the observed selectivity may relate to an adaptation of the moth to the habitat in the UK (*i.e.* dense stands of *Elytrigia* spp.). However, the collapse of *Peucedanum* during the winter makes it a poor over-wintering site for ova and the morphology of *Festuca* may not be suitable as it precludes ovipositing when the leaf sheath is fused to the apex (STACE 1997).

The observed preferred height for oviposition by *G. borelii* (Table 1) corresponds with the part of the grass that supports a loose outer leaf sheath. The chosen height is above the zone of senescence and decomposition of leaf litter, but is low enough to be protected from harsh winter weather. Many of the sites that support *G. borelii* populations in Britain occur along sea walls, and as part of the maintenance of sea defences they are mown annually. If *G. borelii* requires grass of a certain height for oviposition, it is important to ensure that the cutting of grass will enable the grass to be at a suitable height for the moth during the flight period. Currently, much of the sea wall supporting populations of the moth is mown between the end of August and the beginning of September. This period coincides with the pupation/adult stage of *G. borelii* and the flowering/seed dispersal stage of *P. officinale* (Table 2). Therefore, not only is the current management regime detrimental to the emergence and flight of the adult moth, but it results in a short sward, far shorter than the observed average oviposition height (Table 1), being available to the female for oviposition. Also, the period of cutting is before seed dispersal stage of *P. officinale* (Table 2) thus reducing the recruitment rate of this plant.

Elytrigia atherica was the most frequently observed oviposition host and this species is found only within coastal habitats (STACE 1997). However, *G. borelii* was also observed ovipositing on four common grass species with a widespread distribution in the UK. Consequently, it is thought that the ovipositing requirements of *G. borelii* are not the reason why its British distribution is restricted to coastal grassland habitats in the southeast of England. The main reason for the restricted distribution of *G. borelii* seems to be the local distribution of *Peucedanum*. This study provides important information for the proposed strategy of translocation of *G. borelii* colonies further inland in the UK, away from the danger of sea level rise.

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Acknowledgements – The authors would like to thank English Nature, the Cambridgeshire and Essex Branch of Butterfly Conservation, the Environment Agency and Writtle College for providing funding for this study and to the Essex Wildlife Trust and Exchem Organics for allowing access to their land. We are grateful to the following individuals for providing help, advice, information and support: GRAHAM BAILEY, IAN BLACK (English Nature), MALCOLM BRAITHWAITE, DUNCAN BRIDGES, DON DOWN, ROBIN FIELD, JOE FIRMIN, RAY MARSH, TOBY PAYNE, ROGER PILE, COLIN PLANT, SHELAGH REARDON, Dr DAVID SHEPPARD (English Nature), TERRI TARPEY and PAUL WARING. We would like to give a special thank you to TIM GARDINER, MARTIN HEYWOOD, GAVIN SHEILL and LEON WOODROW for the great amount of help they gave with fieldwork and to MICKY ANDREWS for taking some superb photographs.

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Revised version received 17th July, 2002, accepted 30th July, 2002, published 10th August, 2002