Comparison of factors influencing the habitat characteristics of *Gortyna borelii* (Noctuidae) and its larval foodplant *Peucedanum officinale* in the United Kingdom and Germany

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Summary. *Gortyna borelii* is a rare moth species with a widespread, but very localised distribution in Europe. The main larval foodplant of this species is *Peucedanum officinale*. Both *G. borelii* and *P. officinale* are listed as Red Data Book species in United Kingdom and Germany. Little research has been conducted on the ecology of the moth and its larval foodplant in Europe. Both *G. borelii* and *P. officinale* inhabit a range of grassland habitats in Germany, but are restricted to maritime grasslands in Britain. The aim of the study reported in this paper was to compare the physical and vegetation characteristics and abundance of *G. borelii* at sites that support *P. officinale* in both countries. A field study was undertaken at five sites in both countries during the large larval feeding stage of *G. borelii*. The data collected included details of the soil, vegetation composition, density of *P. officinale* and occurrence of *G. borelii* larval feeding signs. The main findings were that *P. officinale* grows within a range of soil conditions, but obtains the greatest growth in acidic soils. *Peucedanum officinale* was found to occur at a lower density in areas that supported a high abundance of tall, coarse grass species. Conversely, a greater abundance of *G. borelii* larval feeding signs tended to be found at sites where tall, coarse grass species were dominant. The results are discussed and related to the management and conservation implications of *P. officinale* and *G. borelii* in both countries.

Zusammenfassung. *Gortyna borelii* ist zwar in vielen Ländern Europas verbreitet, kommt aber überall streng lokal an nur wenigen und eng begrenzten Fundorten vor. In Mitteleuropa ist *Peucedanum officinale* ihre einzige Raupennahrungspflanze. In Großbritannien wie in Deutschland stehen der Falter und die Nahrungspflanze auf den Roten Listen. Um die Zusammenhänge zwischen physikalischen Faktoren, Vegetationsstruktur und der Abundanz von *G. borelii* zu klären, wurden in beiden Ländern je 5 Standorte während der Raupenzeit besucht und Daten über Klima, Höhenlage, Vegetationszusammensetzung, Dichte von *P. officinale* und Raupendichte von *G. borelii* (anhand der Fraßspuren) registriert. Dabei zeigte sich, daß *P. officinale* auf verschiedenen Böden wächst, aber die größten Wuchshöhen auf saurem Boden erreicht. An Standorten, wo heute, harte Gräser große Abundanzen erreichen, kommt *P. officinale* nur in geringer Dichte vor. Dagegen wurden die meisten Raupenfraßspuren von *G. borelii* an Standorten gefunden, wo hohe Grasarten dominierten. Die Ergebnisse werden im Hinblick auf Habitatmanagement und Schutzmaßnahmen diskutiert.

Résumé. *Gortyna borelii* (Pierret, 1837) est une espèce rare, ayant une large répartition en Europe, bien que localisée. La plante nourricière principale de cette espèce est *Peudecanum officinale*. *G. borelii* et *P. officinale*, sont tous deux repris sur la Liste Rouge au Royaume-Uni tant qu'en Allemagne Il n'y a eu que peu de recherche effectuée sur l'écologie de ce papillon et sa plante nourricière en Europe. *G. borelii* et *P. officinale* se trouvent tous deux dans plusieurs types d'herbages en Allemagne, alors qu'en Angleterre ils sont restreints à des herbages côtiers. L'objectif de l'étude rapportée dans le présent article était de comparer les caractéristiques tant physiques que végétationnelles, ainsi que l'abondance de *G. borelii* dans des sites qui abritent *P. officinale* dans les deux pays. Une étude sur le terrain a été conduite sur cinq sites répartis dans les deux pays pendant la longue période correspondant à l'état larvaire de *G. borelii*. Les informations obtenues comprennent des données sur le sol, la composition de la végétation, la densité de *P. officinale* et la présence de traces de consommation par les chenilles de *G. borelii*. Les résultats principaux de l'étude sont que *P. officinale* se trouve sur plusieurs types de sols, mais obtient une croissance maximale sur terrains acides. *P. officinale* a été retrouvé en densité moindre en des endroits comprenant une grande abondance d'espèces de graminées hautes et dures. Au contraire, une plus grande abondance de traces de consommation larvaire de *G. borelii* a pu être observée sur des sites où les graminées hautes et dures prédominaient. Les résultats obtenus sont commentés et mis en rapport aux mesures de conservation et de maintien de *G. borelii* et de *P. officinale* à prévoir dans ces deux pays.

Key words. biogeography, habitat, *Gortyna borelii*, larval foodplant, *Peucedanum officinale*.

Introduction

Gortyna borelii Pierret, 1837 is a large noctuid moth with a very localised, but widespread distribution in Europe. The moth has been recorded in many countries in Central and Southern Europe (Ippolito & Parenzan 1978; Nowacki & Fibiger 1996). In Britain (Bretherton *et al.*, 1983) and Central Europe (Gyulai 1987), the species is classified as the subspecies *lunata* Freyer, 1838. However, there is little evidence that the separation of *G. borelii* into subspecies is justified and therefore the taxonomic status of the moth remains contentious (Steiner 1998; Laszlo Peregovits, pers comm.). The principal larval foodplant of the moth is *Peucedanum officinale* Linnaeus, 1753, but *G. borelii* is also known to feed on *Peucedanum longifolium* L. (Gyulai 1987) and *Peucedanum gallicum* Latour (Dumont 1925–1926).

The altitudinal range of *P. officinale* is from sea level in Britain to about 1800 m in the mountains of Eastern Macedonia and Albania (Randall & Thornton 1996). The highest altitude at which *G. borelii* has been recorded is 1000 m in the Carpathian Basin, Romania, where it feeds on *P. longifolium* (Gyulai 1987). The moth is found within a diversity of habitats: from meadows in forest clearings to limestone mountain ranges in Hungary (Gyulai 1987), from the Paris lowlands to the Upper Rhine Plain (Steiner 1998), and in regularly flooded pasture (König 1959). The populations of the moth in Britain are restricted to maritime habitats in south-east England.

Gortyna borelii has a relatively recent recorded history in England: it was discovered in 1968 and named Fisher's Estuarine Moth (Fisher 1971). The main English populations are located on the north Essex coast. These populations tend to occur <2m above mean sea level and are therefore, vulnerable to sea flooding and the habitat being affected by long-term sea level rise and encroachment of salt marsh (Ringwood *et al.*, 2000). Other threats to the moth include inappropriate management of the sea defences, low population sizes and a lack of understanding of the ecological requirements of the species (Gibson 2000). Due to the tenuous nature of the habitat in which it is found, the moth is included within the British Red Data Book as Category 2 (Vulnerable) (Shirt 1987) and *P. officinale* is listed as Lower Risk (Near Threatened) (Wiggington 1999). *G. borelii* was also added, in 1998, to Schedule 5 of the Wildlife and Countryside Act 1981 (Gibson 2000).

In Germany, *G. borelii* occurs mainly in the south-west of the country, especially in the valleys of the Rhine and its tributaries (in Baden-Württemberg and Rheinland-Pfalz). The species is listed within the German (Pretscher 1998) and Baden-Württemberg (Ebert 1998) Red Data Books as Category 1 (Threatened by Extinction), and is also protected under Federal Nature Protection Law 1987. Similarly, *P. officinale* is included within the German and Baden-Württemberg Red Data Books as Category 3 (Threatened) (Sebald *et al.* 1992). Steiner (1998) mentions that the main threats to *G. borelii* in Germany are the fragmentation and destruction of meadows with *P. officinale* by urbanisation or agricultural use, flooding and intensive mowing.

The phenology of this species in Germany (Steiner 1998) is virtually the same as that in England (Heath & Emmet 1983; Skinner 1998; Gibson 2000). Diapause occurs in the ovum and the eggs hatch during April/May, the larval stages then develop to

August, with pupation occurring in August/September. This is followed by the flight period from September–October. During ovipositing, the ova are deposited beneath the outer leaf sheath of grass stems (Ippolito & Parenzan 1978; Platts 1981; Steiner 1998). Observations in England have shown a preference in ovipositing for *Elytrigia atherica*, which has a loose pseudostem construction (Ringwood *et al.* 2000). The larvae are stem borers: feeding first within the stems of *P. officinale* before moving down, during the mature larval stages, to the rootstock, where pupation occurs.

There are plans to establish colonies of *G. borelii* further inland, away from the threats of sea level rise, to secure the long-term future of the species in England (Ringwood *et al.* 2000). However, before such plans can be developed it would be beneficial to examine aspects of soil conditions, vegetation structure and habitat characteristics that support populations of the species in continental Europe, away from maritime environments.

The objectives of this paper are to present results from a study that compared sites in Germany (Baden-Württemberg) and in England that may support populations of *G. borelii*. The sites are compared in terms of climatological and geological information with field studies enabling details of the soil conditions, vegetation structure, density of *P. officinale* and incidence of the moth's larval feeding signs to be reported. In determining the habitat requirements of *G. borelii* factors such as larval foodplant density, sward composition and the effects of soil pH and nutrient status on the growth of *P. officinale* were also examined. The results are discussed in terms of environmental management and the conservation implications for this species in each of these countries.

Materials and Methods

Ten sites in England and Germany were examined in the study. In England, the five sites chosen were located within 3.5 km of each other in the Walton Backwaters area of the north Essex coast. The close proximity of the sites chosen in England was due to the restricted distribution of *G. borelii* in this country. A view across the Walton Backwaters area is shown in Plate 1. The Walton Backwaters covers an area of around 800 ha and is of particular environmental importance (Yearsley 1994). Hamford Water is the main creek that runs through the area and consists of constantly changing marshland and a number of islands. The Hamford Water is a Site of Special Scientific Interest, Special Protection Area and Ramsar Site (Countryside Agency 2000). The underlying geology of the area is a Palaeogene clay basin overlain by Neogene and early Pleistocene crag deposits with little or no drift geology. The mean annual temperature and precipitation of the area are 10–11°C and 400–500 mm respectively. All sites are located at an altitude of less than 5 m OD. The five sites selected for field studies were Beaumont Quay, Bramble Island, Old Moze, Skipper's East and Skipper's West. Details of the characteristics of each of these sites are given in Table 1.

In contrast to the English sites, the sites in Germany are spread over a wide geographical area and are up to 300 km apart. Four of the sites are in Baden-Württemberg (Speyer, Tübingen 1, Tübingen 2 and Zellerhorn) and one in Rheinland-Pfalz

(Oberhausen). The steep, rocky slope that characterises the Oberhausen site is shown in Plate 2. A description of each of the German sites is provided in Table 2 and reports

Plate 1. The Walton Backwaters area (view towards Skipper's Island). Photo credit: Zoë Ringwood.

Table 1. Characteristics of the English sites.

Site	Status	Site description	Altitude (m)	Management	Threats
Beaumont Quay	National Nature Reserve	Long, rank, unimproved grassland on and behind a sea defense wall	1-3	Mown annually	None perceived
Bramble Island	Privately owned	Grassland within an industrial area	4-5	Mown regularly	Intensive mowing
Old Moze	Privately owned	Coarse unimproved grassland on and behind a steep, well maintained sea wall	1-4	None	None perceived
Skipper's East	National Nature Reserve	Coastal grassland located between the sea wall and scrub	<2	None	Flooding and scrub encroachment
Skipper's West	National Nature Reserve	Coastal grassland located between eroding sea defences and scrub	<2	None	Flooding and scrub encroachment

Plate 2. The steep, rocky slope at Oberhausen. Photo credit: Zoë Ringwood.

Table 2. Characteristics of the German sites.

Site	Status	Site description	Geology	Altitude (m)	Management	Threats
Oberhausen	Privately owned	Dry grassland and scrub on a steep, rocky southerly facing slope	Permian	180-250	None	Scrub encroachment to certain areas
Speyer	Part Nature Reserve	Moderately dry grassland on an alluvial plain	Alluvial	100	Mown regularly	Unsympathetic management regime
Tübingen 1	Nature Reserve	A southerly facing slope with unimproved grassland and scrub	Triassic	400-460	Mown every third or fourth year	None perceived
Tübingen 2	Nature Reserve	Dry grassland situated between vineyards and a forested area	Triassic	510-530	Removal of scrub every third or fourth year	Scrub encroachment
Zellerhorn	Nature Reserve	Dry calcareous grassland located on a level area of a northerly facing slope	Jurassic	830-850	Periodic mowing	None perceived

that the altitude and underlying geology varies considerably between the sites. At Oberhausen, Speyer and Tübingen 1, the mean annual temperature is about 9°C and the mean annual precipitation is around 600 mm. However, at Tübingen 2 the mean annual temperature and precipitation are 7–8°C and 700–800 mm respectively. Zellerhorn is the coldest and wettest of the sites with an average annual temperature of 6°C and approximately 800–900 mm of rainfall recorded each year.

Field Survey

The five English and five German sites were surveyed between the 25th June and 10th July 2001. Ten 1 m^2 quadrats were placed randomly within the area of the main stands of *P. officinale* at each of the ten sites surveyed. The number of *P. officinale* plants, height and width of each of these plants, and the height of the surrounding grass were measured in each of the quadrats. The percentage ground coverage was estimated by visual assessment (Bullock 1996) for each of the other vegetation species present (including grasses) in each quadrat. A sward classification system that grouped sward characteristics into density categories (Table 3) was used to provide information on the density of the sward within each of the quadrats.

Table 3. The density categories in the sward classification system.

Category	Description
0	>75% bare earth
1	Predominantly short (<0.25m) grass with 6-75% bare earth
2	Predominantly short (<0.25m) grass with <5% bare earth
3	A sward, mainly <0.5m in height, consisting of both fine leafed and coarse grass species
4	Tall (>0.5m) dense, coarse grass interspersed with patches of shorter grass
5	Tall (>1m), dense, coarse grass with a uniform sward height

In addition to the quadrat surveys, fifty *P. officinale* plants were examined at each of the sites for the presence of *G. borelii* larval feeding signs (bore holes and/or frass piles within the stems, stem axils or at the base of the plant). This was conducted to obtain an indication of the abundance of this moth at each of the sites surveyed. The larval feeding signs of this species are very distinctive (Steiner 1985) and therefore cannot be confused with any other species of Lepidoptera.

Soil samples were taken to a depth of 25 cm from every site in the survey and analysed for pH, available phosphorus, potassium and magnesium and conductivity according to MAFF (1986).

Statistical Analysis

The data collected in the survey were non-parametric and therefore appropriate tests were conducted. Spearman's Rank correlation coefficient R_S (Heath 1995) was performed to determine the relationships between mean *P. officinale* height and soil pH, conductivity and available soil magnesium, phosphorus and potassium at each of the sites. The test was also performed to determine the relationship between the proportion of *P. officinale* plants with *G. borelii* feeding signs, the mean number of *P. officinale* individuals per m^2, mean *P. officinale* height and mean sward height at each of the sites.

Czekanowski's coefficient (Kent & Coker 1992) was used to determine the botanical similarity between each of the sites in England and Germany. A chi-squared (χ^2) test of association (Heath 1995) was conducted between the presence and absence of *P. officinale* and the most abundant grass species within quadrats in England and Germany. The English and German sites were grouped when performing this test. Mann-Whitney *U*-test (Heath 1995) was used to determine if differences existed between the mean sward height at sites in England and Germany and also between the mean *P. officinale* height in both countries.

Results

The soil conditions at sites in England and Germany varied considerably (Table 4). The sites in England were characterised by soils of acidic nature and medium to heavy texture (predominantly sandy silt loams or clay loams). However, in Germany the soils were predominantly alkaline and medium to heavy texture (sandy loam, clay loams or clay). The exception was the site of Oberhausen which had acidic soils of light textural classification (loamy sand). The nutrient status of the soils varied considerably, for example, concentrations of available phosphorus levels ranged from 4.0 mg/l at Zellerhorn to 23.4 mg/l at Bramble Island. The concentrations of available magnesium were very varied, ranging from 62 mg/l at Speyer to 988 mg/l at Tübingen 2. Similarly, the concentrations of available potassium differed considerably between sites. The conductivity of soil solutions extracted from the various sites were relatively low in England and Germany.

The relationship between soil pH and mean *P. officinale* height is illustrated in Figure 1. There was found to be a significant negative correlation between the two factors (Table 5). No significant relationships were detected between *P. officinale* height and the major soil nutrients. A significant positive correlation was, however, observed between soil conductivity and *P. officinale* height (Table 5).

A greater botanical species richness was recorded at the German sites (Table 6). At Zellerhorn, for example, a total of 40 species were recorded in the quadrat survey, with a maximum of 21 species per m^2. Comparatively, at Skipper's East, nine species were noted, with a maximum of three species per m^2. The vegetation at the English sites displayed some similarity in species composition (Table 7).

Table 4. Soil characteristics of the English and German sites.

English Sites	**pH**	**P (mg/l)**	**Mg (mg/l)**	**K (mg/l)**	**Conductivity (µS/cm)**	**Texture**
Beaumont Quay	5.8	20.6	321	451	2345	Clay loam
Bramble Island	5.4	23.4	399	732	3004	Clay loam
Old Moze	5.8	12.0	212	313	2102	Sandy silt loam
Skipper's East	6.2	9.2	324	638	2240	Sandy silt loam
Skipper's West	6.6	10.0	334	865	2377	Clay loam
German sites						
Oberhausen	6.4	15.8	106	769	1934	Loamy sand
Speyer	7.9	14.2	62	105	2000	Sandy loam
Tübingen 1	8.3	5.4	209	355	1992	Clay loam
Tübingen 2	8.1	7.2	441	988	1971	Clay
Zellerhorn	8.1	4.0	120	133	1983	Clay loam

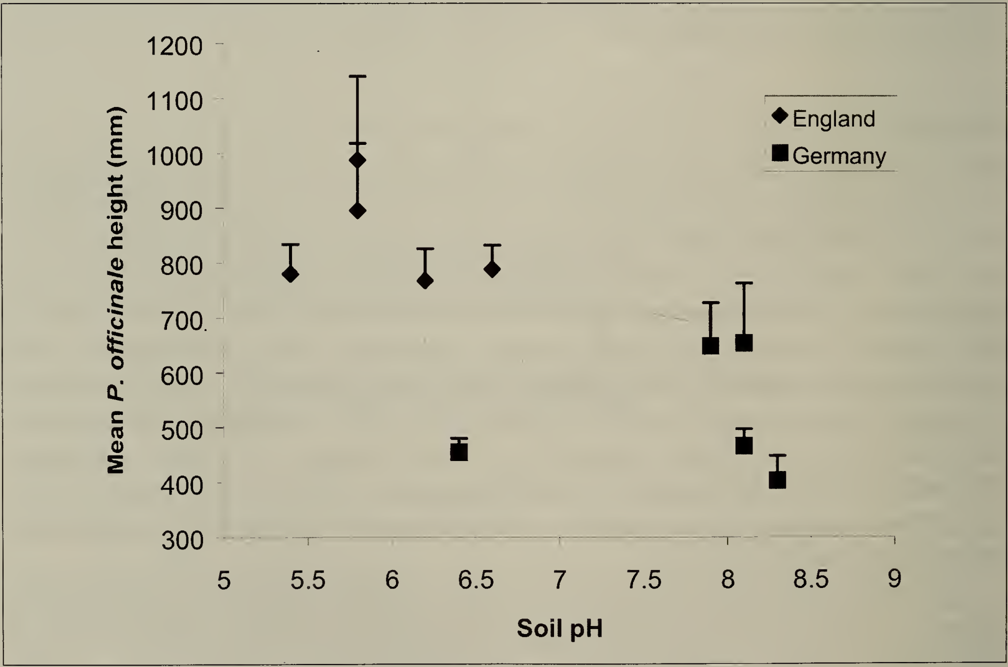

Figure 1. Relationship between soil pH and mean *P. officinale* height (s. e. bars shown).

For example, Beaumont Quay was particularly similar to Old Moze and Skipper's East. The coarse grass species *Arrhenatherum elatius* and *Elytrigia atherica* dominate these three sites (Table 8). In comparison, the German sites displayed a lower level of similarity in species composition (Table 7), especially between Zellerhorn and Tübingen 2, and Speyer and Tübingen 1. In addition to the differences in species richness at

Table 5. The correlation (R_S) between mean *P. officinale* height and soil pH, nutrient content and conductivity. * – significant at $p<0.05$.

Correlation Factors	R_S (probability level)
Soil pH	-0.732 (p<0.016)*
Soil magnesium	+0.515 (p<0.128)
Soil phosphorous	+0.479 (p<0.162)
Soil potassium	+0.139 (p<0.701)
Soil conductivity	+0.733 (p<0.016)*

Table 6. Botanical characteristics of English and German sites.

English Sites	No. spp.	Mean no. spp. / m^2	Range in No. spp. / m^2
Beaumont Quay	21	5.9	2 - 13
Bramble Island	19	7.1	3 - 10
Old Moze	10	4.9	3 - 6
Skipper's East	9	2.5	1 - 3
Skipper's West	12	3.7	3 - 6
German sites			
Oberhausen	17	5.0	3 - 7
Speyer	24	7.4	4 - 10
Tuebingen 1	22	8.9	6 - 12
Tuebingen 2	27	8.1	4 - 11
Zellerhorn	40	16.1	12 - 21

these sites (Table 6), the most abundant grass species were also dissimilar (Table 8). For example, at Zellerhorn the main grass species were *Briza media* and *Festuca pratensis*, in comparison with *A. elatius* and *Bromopsis erecta* at Tübingen 2. The sites in England and Germany display a low level of similarity in grassland botanical characteristics (Table 7). In fact, the only similarity between certain sites in England and Germany was the presence of *P. officinale*.

The incidence of *P. officinale* was found to be associated with the coarse grass species *A. elatius* (χ^2: 8.74, P<0.01) and *Elytrigia* spp. (χ^2: 10.50, P<0.01) in England (Table 9). *Peucedanum officinale* did not tend to occur in great abundance with these two coarse grass species and therefore the association was negative. In Germany, *P. officinale* was negatively associated with the presence of *B. erecta* (χ^2: 5.40, P<0.05). A difference (Mann-Whitney test, Z = 6.61, P<0.001) was detected between mean sward height in England and Germany, with the English sites supporting taller swards (Table 8). A difference (Mann-Whitney test, Z = 7.61, P<0.001) was also found in mean *P. officinale* height between the sites in England and Germany with a clear trend of mean height of the larval host plant being greater at English sites. The relationship between mean *P. officinale* height and mean sward height at the sites (R_S = 0.903, P<0.001) in the study is illustrated in Figure 2.

The proportion of *P. officinale* plants with *G. borelii* feeding signs at the English sites ranged from 0.04 at Bramble Island to 0.54 at Skipper's East (Table 8). However, in Germany *G. borelii* was not recorded from Zellerhorn, whereas at Tübingen 2 the proportion of *P. officinale* with larval feeding signs was 0.34. The relationship between the mean number of *P. officinale* individuals per m^2 and the proportion of *P. officinale* plants with *G. borelii* feeding signs is illustrated in Figure 3. A negative correlation was observed between the two factors (Table 10). There was no significant relationship found between mean *P. officinale* height and the proportion of *P. officinale* with *G. borelii* feeding signs, or between mean sward height and the proportion of *P. officinale* plants with *G. borelii* feeding signs (Table 10).

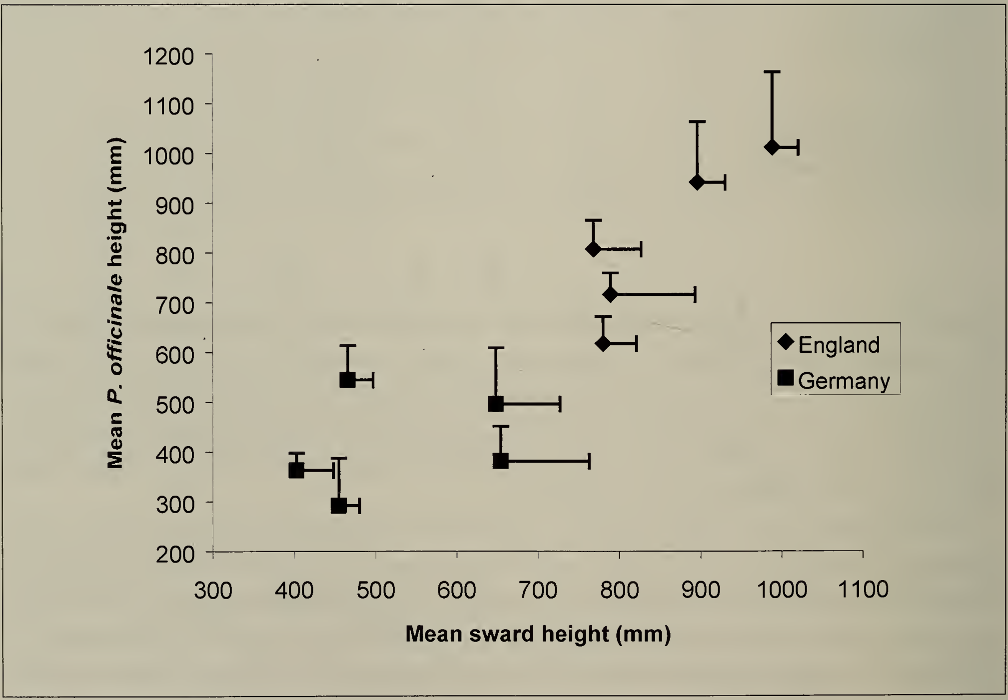

Figure 2. Relationship between mean sward height and mean *P. officinale* height (s. e. bars shown).

Discussion

Many environmental differences between the sites in England and Germany were observed, including climate, topographical variation, soil, habitat and vegetative composition. Climatic differences are due to many variables, for example, the coastal nature of the English sites and the fact that the climate of the German sites is continental. *P.*

Table 7. Similarity matrix of Czekanowski coefficients calculated between the 10 sites surveyed.

	English Sites					German Sites			
	Bramble Island	**Beaumont Quay**	**Old Moze**	**Skippers East**	**Skippers West**	**Oberhausen**	**Speyer**	**Tübingen 1**	**Tübingen 2**
Beaumont Quay	0.41	–							
Old Moze	0.49	0.82	–						
Skippers East	0.44	0.61	0.56	–					
Skippers West	0.63	0.39	0.55	0.60	–				
Oberhausen	0.28	0.29	0.26	0.23	0.33	–			
Speyer	0.24	0.36	0.34	0.22	0.27	0.25	–		
Tübingen1	0.13	0.13	0.13	0.12	0.15	0.22	0.13	–	
Tübingen2	0.16	0.17	0.18	0.11	0.20	0.28	0.22	0.41	–
Zellerhorn	0.31	0.22	0.23	0.40	0.39	0.29	0.20	0.23	0.16

Table 8. The most abundant grass spp., sward height and density (using sward density classification as in Table 3) and the proportion of *P. officinale* plants with *G. borelii* feeding signs at each of the English and German sites.

English Sites	**Abundant grass spp.**	**Mean sward height (s. e.)(mm)**	***Median sward density**	**Proportion with *G. borelii***
Skipper's East	*Arrhenatherum elatius, Elytrigia atherica*	808 (59)	4	0.54
Beaumont Quay	*Arrhenatherum elatius, Elytrigia atherica*	1012 (32)	4	0.30
Old Moze	*Arrhenatherum elatius, Elytrigia atherica*	942 (34)	4	0.30
Skipper's West	*Holcus lanatus, Festuca rubra*	717 (104)	3	0.22
Bramble Island	*Holcus lanatus*	618 (41)	3	0.04
German sites				
Tübingen 2	*Arrhenatherum elatius, Bromopsis erecta*	386 (70)	2	0.34
Tübingen 1	*Bromopsis erecta, Molinia caerulea*	363 (35)	3	0.22
Oberhausen	*Arrhenatherum elatius, Bromopsis erecta*	292 (96)	2	0.08
Speyer	*Arrhenatherum elatius, Elytrigia repens*	497 (113)	4	0.08
Zellerhorn	*Briza media, Festuca pratensis*	545 (70)	2	0.00

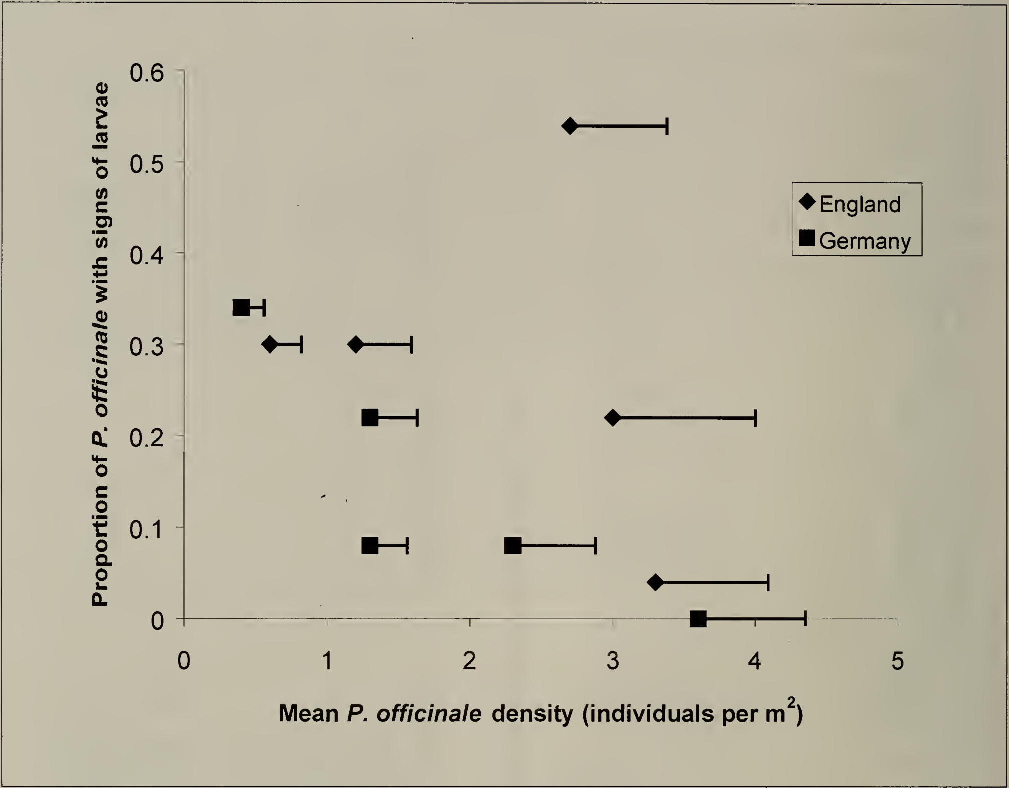

Figure 3. Relationship between mean *P. officinale* density (s. e. bars shown) and the proportion of *P. officinale* plants with signs of *G. borelii* larval feeding.

Table 9. Associations between *P. officinale* and the most abundant grass species in grouped English and German sites. Given are χ^2 values (with 1 d.f.). NR – not recorded. * – significant at $p<0.05$; ** – significant at $p<0.01$.

Grass species	England	Germany
Arrhenatherum elatius	8.74**	1.70
Bromopsis erecta	NR	5.40*
Dactylis glomerata	0.70	0.30
Elytrigia spp	10.50**	0.93
Festuca spp	0.65	0.02
Holcus lanatus	0.28	0.08

officinale showed a degree of adaptability in relation to its ability to withstand a variety of climatic conditions and altitudes observed in this study. However, the absence of the moth at Zellerhorn is suggested to be in response to poor adaptation to the adverse climatic conditions at the site.

In England, *P. officinale* is a plant of coastal grassland, growing on heavy clays and recent alluvial deposits (Thornton 1990). The German populations are generally found in calcareous grasslands, particularly near rivers and in mountainous meadows (Randall

Table 10. The correlation (R_S) between the proportion of *P. officinale* plants with *G. borelii* feeding signs and *P. officinale* density, mean *P. officinale* height and mean sward height. * – significant at $p<0.05$.

Correlation Factors	R_S (probability level)
P. officinale density	-0.644 (p<0.044)*
Mean P. officinale height	+0.398 (p<0.255)
Mean sward height	+0.379 (p<0.280)

& Thornton 1996). The grasslands in both countries, however, tend to be unimproved. The English populations occur within species-poor unimproved grassland, whereas in Germany the plant tends to grow in species-rich meadows (Table 6).

The grassland areas in England that support *P. officinale* display a level of similarity, but the vegetation composition of the German sites was more varied (Table 7). This may be due to the differences in altitude and climate within the sites in Germany (Table 2), or the fact that the German sites were generally located a considerable distance from each other. *Peucedanum officinale* was observed in greatest abundance at sites where it was not in competition with dominant, coarse grass species, such as *A. elatius*, *E. atherica* and *B. erecta*. It was observed that very dense swards where these species are abundant support a very low density of *P. officinale*. Randall & Thornton (1996) state that initial establishment of *P. officinale* is reduced by dominant grass species. This is tentatively supported by the observations that *P. officinale* was significantly negatively associated *with A. elatius*, *B. erecta* and *Elytrigia* spp. (Table 9), and did not tend to occur in great abundance with these coarse grass species.

The mean sward and *P. officinale* height were significantly greater within the English sites. This may be due to a number of factors, including climate, altitude, topography and soil conditions. The climate and altitude at the German sites were very different to those in England (Tables 1 & 2). The topographic conditions in Germany were predominantly quite extreme with steep rocky slopes at several sites. These conditions tend to support thin, well-drained soils, which do not provide optimal growing conditions for many species of plant. The survey results indicate that pH (Figure 1) and soil conductivity may be important factors in determining the growth of *P. officinale*, but that this plant species is tolerant of a range of soil conditions. However, the relationship between *P. officinale* height and soil conductivity may be misleading, as although a significant positive correlation was calculated between these factors (Table 5), the soil conductivity levels at all the sites were relatively low and the range of conductivity was relatively narrow. Also, *P. officinale* does not grow on salt marsh in England even though it is associated to coastal habitats.

The density of *P. officinale* within a sward was found to have an influence on the abundance of *G. borelii*. Sites in the study with a low density of *P. officinale* were generally observed to have the greatest proportion of *G. borelii* larval feeding signs (Figure 3). The sites in England with the greatest proportion of *G. borelii* larval feeding signs support very tall and dense swards (Table 8). Hart (1999) also observed that the most favoured sites for the larvae occur where *P. officinale* grows amongst long, rank grass. The reasons for this may be due to the ovipositing requirements of this species. Ringwood *et al.* (2000) observed that in England *G. borelii* has oviposition preferences for *Elytrigia* spp., but the moth has also been observed egg laying on *A. elatius* and *D. glomerata* (Ringwood *et al.* 2002 and unpublished data). These coarse grass species tend to dominate grasslands, but also restrict the abundance of *P. officinale*. It is, however, essential for coarse grasses to be present, providing an abundance of oviposition hosts for the moth in England. However, the host plants for ovipositing in Germany have not been recorded and further studies are required. The results from this study suggest that *B. erecta* and *A. elatius* are potential oviposition host plants in Germany, as they are the predominant grass species at most of the sites. The availability of suitable grass species during the flight period may be an important management consideration.

Inappropriate mowing regimes at some of the English and German sites may pose a threat to the survival of the moth and *P. officinale*. For instance, at Bramble Island (Table 1) and Speyer (Table 2) the sites were mown regularly and neither appears to support a large colony of *G. borelii* (Table 8). Another serious threat to colonies in both countries is scrub encroachment, which is particularly serious at Skipper's East and West and Tübingen 2. We suggest that some form of scrub control is necessary, with mowing being the most practical solution at most of the sites. However, the intensity and time of year when mowing is conducted needs very careful consideration. Gibson (2000) states that mowing during the flight period (September–October) may be detrimental to *G. borelii* as adult moths and eggs may be damaged. August may be a more appropriate time of year to mow as the larva is feeding and pupating under ground (Hart 1999). However, mowing at this time of year may prevent the grass growing sufficiently to provide suitable oviposition sites. Further research aimed at determining the most appropriate management is being undertaken in England.

Management recommendations in England must also include the consideration of sea level rise and the risk of sea flooding at certain sites. Skipper's Island, which is thought to contain over 70% of the English *G. borelii* population (Tarpey 1999), is under serious threat from the impending rise in sea level. Indeed, almost the entire English population of this moth may be lost at any time as a result of a single surge tide. Thus, the establishment of populations of this species further inland may be paramount to its survival in England. The German populations are able to persist a considerable distance from the sea, in a wide range of habitats, soil conditions and at altitudes with a more extreme climate. This may indicate that English populations may be able to persist at locations away from coastal environments. However, further research is needed into the ecological requirements of *P. officinale* and *G. borelii* in both countries.

G. borelii has a widespread, but very localised European distribution. In many countries where it is found, the species is rare and has some form of legal protection. The main reason for the rarity of this moth is probably the limited distribution of *P. officinale*. As the plant has been found to grow within a diversity of unimproved grasslands, it is thought that the limited distribution may be largely due to the human actions of urbanisation, agricultural intensification and other changes in land use. It must now be decided whether human intervention should be used to the benefit of both the moth and its foodplant by establishing colonies of *P. officinale* and consequently securing the future of *G. borelii*.

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