Habitat quality assessment and its role in the conservation of the butterfly *Melitaea cinxia*

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Ultimately, the successful conservation of wildlife depends on the presence of sufficient habitat of adequate quality. This paper presents an index based on 11 factors to rate habitat quality for the Glanville fritillary butterfly, *Melitaea cinxia*. The index explained 73% of the occupancy of *M. cinxia* on 40 sites in Belgium and The Netherlands. The six most significant factors were: the Ellenberg acidity and productivity values, the presence of standing dead vegetation, diversity in vegetation structure, host plant density and the proportion of open field bordering the site. The index appears a promising tool in the planning of measures for habitat restoration.

**Keywords**: nature conservation, Lepidoptera, butterflies, habitat quality index, *Melitaea cinxia*

The persistence of endangered species is threatened by three main processes, which may act simultaneously: habitat loss, fragmentation and decrease of habitat quality. In butterflies, patch size and isolation are of paramount importance for the establishment and persistence of some species (Hanski & Thomas 1994). However, habitat quality can be equally important (Dennis & Eales 1997). The Glanville fritillary, *Melitaea cinxia*, has been the subject of extensive study in the Åland archipelago of South Finland, where the importance of patch size and isolation in determining patch occupancy has been well established (Hanski, 1994; Hanski et al., 1995, 1996). However, variation in habitat quality is clearly an important additional factor (Hanski et al., 1994, 1996). Although Moilanen & Hanski (1998) found that environmental factors added little to the incidence function model for patch occupancy of *M. cinxia*, which is based purely on colonisation-extinction dynamics, this does not mean that habitat quality is of trivial importance. Notably, as acknowledged by the authors, the GIS data used in that study have a grid size that is too course in comparison with the spatial scale that is important for the butterfly.

It is appropriate to place more emphasis on habitat quality is when habitat restoration of a threatened species is envisaged. For a species that faces regional extinction, as is the case for *M. cinxia* in The Netherlands (Van Ommering et al., 1995) and in Belgium (Maes & Van Dyck, 1996), survival is likely to depend primarily on the maintenance and restoration of habitat quality, only to be followed by the creation of a network of habitat patches once source populations can build up and expand. Of course the two steps of restoring quality and area should go hand in hand, but in the initial phase it is crucial to have an exact knowledge of the main factors determining habitat quality.

In general, habitat quality for butterflies is determined by the presence of nectar sources, specific host plants, and a particular vegetation structure to provide a suitable microclimate (Bink, 1992; Thomas & Lewington, 1991). For each species the specific requirements usually differ. A simple habitat quality-index on the basis of four characteristics was developed by Hanski et al. (1994), but this only covered a limited part of the butterfly’s life cycle. In this paper I offer new data on habitat characteristics and propose a more elaborate index to rate habitat quality for *M. cinxia*.

**Distribution and life history of *M. cinxia***

The Glanville fritillary, *Melitaea cinxia*, is a butterfly from dry grasslands with a diverse structure and an abundance of flowering plants. The species has a large Eurasian distribution. In Europe its northern limit coincides with a July isotherm of 16.5-17.0°C. In all of North-Western Europe the species shows a decline, which has been especially pronounced in The Netherlands and Belgium (Van Swaay & Warren, 1999). In The Netherlands the species is currently believed extinct since
1995, which has led to a species protection plan aiming at its re-establishment by recolonisation from neighbouring populations in Belgium (WallisDeVries, 2001).

The flight period of *M. cinxia* peaks between mid-May and mid-June (Bink, 1992; Thomas & Lewington, 1991). The butterflies are fairly mobile with 20% covering more than 1 km (Hanksi *et al.*, 1994 and 1995). They are attracted by richly flowering grasslands (Kuussaari *et al.*, 1996); in The Netherlands and Belgium *Centauraea jacea*, *Leucanthemum vulgare* and *Hypochaeris radicata* are main nectar sources (WallisDeVries, 1998). Butterfly emigration is enhanced by a poor nectar supply and by open fields adjacent to habitat patches (Kuussaari *et al.*, 1996). Oviposition typically occurs in clusters of 100-200 eggs on the underside of the leaves of its host plant, predominantly *Plantago lanceolata* in The Netherlands and Belgium (Thomas & Lewington, 1991; Bink, 1992). Larval habitat patches are typically small (median 300 m²; Hanksi *et al.*, 1995) and scattered over the landscape. The caterpillars live gregariously in a web on the host plant. They hibernate in a densely woven web, but the structure of the vegetation in which hibernation takes place has not been well described. The larvae remain together in spring until the final instar. Their black colour and gregarious behaviour is regarded as an adaptation to meet thermal requirements and larvae are frequently seen basking on dead vegetation (WallisDeVries, 1998). In addition, the structure of the vegetation in which they feed is open and plant productivity is low to intermediate, which adds to a warmer microclimate (Simcox & Thomas, 1979; Thomas & Lewington, 1991; Hanksi *et al.*, 1994). South-facing slopes provide an even warmer and probably more preferred microclimate at the northern edge of the species' range (Simcox & Thomas, 1979). As the food requirement of a larval group continues to increase and larval mobility is limited to a few meters, the required *Plantago* density is high; two independent estimates of the minimum density for an average nest of 44 larvae gave the same value of 7 small plants/m² (WallisDeVries, 1998). M. Kuussaari (pers. comm.) found an average density of 10.3 plants/m². At the final instar, caterpillars are more mobile and disperse to pupate in dense vegetation (Thomas & Lewington, 1991).

**METHODS**

**Habitat characteristics**

Characteristics of habitat quality were investigated in three populations in Flanders near Zutendaal, Wezel and Meeuwen-Gruitrode during 1998 (with additional data collected in 2000). Those factors known or suspected to be of importance but not well-described were given special attention (see also WallisDeVries, 1998): host plant density, vegetation height at hibernation sites and Ellenberg site indicator values.

Host plant density was estimated in 1 m² around the spring nests in the populations of Zutendaal and Meeuwen-Gruitrode. Vegetation height at and around each spring and autumn nests was determined in two crosswise 2-m transects, in N-S and W-E directions, intersecting at the nest itself. Height measurements were carried out with a light tempex disc (8 g, 10 cm diameter) lowered gently along a wooden rod onto the vegetation

Ellenberg indicator values have been used successfully by Oostermeijer & Van Swaay (1998) to characterise abiotic conditions of butterfly habitats. Site indicator values on a scale from 1 to 9 were calculated for acidity (1=acid, 9=calcareous), productivity (also known as nitrogen value (1=poor, 9=rich) and moisture (1=dry, 9=wet) from plant species lists for 45 sites, excluding rare species. Of these sites, 15 had been occupied by *M. cinxia* in the 1990s (including the above populations, a site near Olmen in Flanders and along the Julianakanaal in The Netherlands) and 30 sites were chosen from dry grassland sites in the vicinity of these populations. In the calculation the contributions of individual species were averaged without weighting according to their cover. The same sites were surveyed for nectar plant abundance. All these sites were located on sandy to sandy-loamy soils. For comparison, 6 sites were surveyed on calcareous soils in the area of an introduced population near Lanaye, Belgium. Logistic regression was used, as in Oostermeijer & Van Swaay (1998), to derive optimal values for occupied patches.
Table 1. Factors included in the habitat quality index for *Melitaea cinxia* and their values for low, moderate or high quality habitat; the respective index values for low, moderate and high quality are –2, 0 and 1. Variation in (micro)topography was so low in the study areas that this factor was left out of the final index.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Quality</th>
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<tbody>
<tr>
<td>Low</td>
<td>Moderate</td>
</tr>
<tr>
<td>Plantago density (N/m²)¹</td>
<td>&lt;1</td>
</tr>
<tr>
<td>% Cover short vegetation (&lt;5 cm)</td>
<td>&lt;5</td>
</tr>
<tr>
<td>% Cover standing dead vegetation</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Scale of structural diversity (m)</td>
<td>&gt;50</td>
</tr>
<tr>
<td>Nectar abundance (flowers/m²)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Ellenberg acidity value</td>
<td>&lt;3.8</td>
</tr>
<tr>
<td>Ellenberg productivity value</td>
<td>&gt;5.7</td>
</tr>
<tr>
<td>Ellenberg moisture value</td>
<td>&gt;5.8</td>
</tr>
<tr>
<td>Open field border (%)</td>
<td>&gt;75%</td>
</tr>
<tr>
<td>Sun</td>
<td>Shady</td>
</tr>
<tr>
<td>Shelter</td>
<td>None</td>
</tr>
<tr>
<td>(Micro)topography</td>
<td>None</td>
</tr>
</tbody>
</table>

¹ A 'very low' category (index value –4) was given when density was <0.1

**Habitat quality index**

The habitat quality index was designed to classify various components of habitat patches in terms of low, moderate or high quality (Table 1). The importance of all factors has been shown either in the above-mentioned studies or in the present study, although the factors 'sun' and 'shelter' are merely surmised from general microclimatic considerations. The index is calculated as the sum of the values for the various quality components, with –2 for 'low', 0 for 'moderate' and 1 for 'high'. Thus, low quality weighs heavy but a cut-off point for complete unsuitability was not included. Boundary values were derived from field data and from other studies. Topography has not been presented in the data and index values, as only a few areas showed any relief.

A preliminary test of the predictive power of the habitat quality index was performed at a scale of 50x50 m, which lowered the number of sites to 40 (with 8 recently occupied), by logistic regression of the index on actual or recent occupancy. As an illustration of practical application, a slightly modified index was used in 2000 to rate 100 sites (including the sites of Olmen and Wezel) in a 65 km² area around Balen in Flanders. This time, sites were chosen on the basis of the occurrence of *Plantago* concentrations (>10 plants/m² on >10 m²) instead of selecting dry grasslands. This provides a more practical and less ambiguous selection criterion in field surveys. Consequently, the host plant density criterion in the index was replaced by an area criterion (based on Hanski, 1994): low quality 10-100 m², moderate quality 100-1000 m² and high quality >1000 m² of high *Plantago* density.

**RESULTS**

**General site characteristics**

The vegetation of occupied patches showed a high frequency of occurrence (>60%) for the following plant species: *Plantago lanceolata*, *Achillea millefolium*, *Festuca rubra*, *Vicia hirsuta*, *Hypericum perforatum*, *Holcus lanatus*, *Vicia sativa* ssp. *nigra*, *Trifolium dubium* and the main nectar plant *Centaurea jacea*. Nectar abundance typically ranged in the order of 1-10 flowers/m².

On sandy soils occupied patches were located on sites of intermediate acidity and productivity (Fig. 1). On these soils acidity and productivity values are significantly correlated (r=+0.89, P<0.0001). The optimal acidity value was 4.9 with a tolerance of 0.5 and a maximum probability of occurrence of 0.60 (P=0.0003). The optimal productivity value was 4.8 with a tolerance of 0.5 and a maximum probability of occurrence of 0.61 (P=0.004). No relation was found between occupancy and moisture value, but this was probably due to the narrow range of conditions sampled in this respect. The average moisture value of occupied patches was 4.8±0.5 (±95% confidence interval). The sites on calcareous soils showed that *M. cinxia* may also occur at high acidity values and at low productivity values.
At the scale of 50x50 m habitat patches were secluded with only 33±17% (±95% confidence interval) of the perimeter bordering open fields.

**Larval habitat**

Host plant densities around larval nests in spring averaged 29.0±14.6 per m² (N=9) in Meeuwen-Gruitrode and 23.7±12.0 per m² (N=16) in Zutendaal, which is well above the calculated minimum density. In April 70-85% of the vegetation on larval sites was less than 15 cm high, with 20% less than 5 cm. This confirms the open nature of the vegetation structure of caterpillar feeding sites. In contrast, hibernation nests were located in comparatively tall vegetation: 20.9±10.6 cm (N=19) in Zutendaal and 13.7±5.2 cm (N=18) in Wezel. This vegetation typically consisted of standing dead grasses. The nests themselves were always suspended at some height above ground level, with a respective median of 8 and 5 cm for the two populations. In Wezel, all the surrounding vegetation was shorter (9.7±3.3 cm; P=0.0005), whereas in Zutendaal only the vegetation on the sun-facing southern and eastern sides was shorter (15.0±5.8 cm; P=0.004). In other words, the vegetation around larvae nests showed structural diversity with short vegetation adjacent to tall vegetation.

**Preliminary test of the habitat quality index**

The index values of 40 vacant and occupied sites ranged between –10 and +11; the lowest value for occupied sites was 5. The full index explained 61.1% of the variation in patch occupancy (Fig. 2). However, some components of the index rather decreased than raised the proportion of explained variation. A stepwise regression approach (Table 2) identified four main and two less important factors out of the original 11 factors, which explained 72.7% of patch occupancy.

**Practical application**

The site survey in the area around Balen revealed significant differences in the habitat quality index between the four main habitat types and the four main types of site management (Fig. 3). Unmanaged ruderal areas and canal verges managed at low intensity were most promising, even though the average index was low. The worst habitat quality was found in meadows or in pastures grazed by other livestock than horses, i.e. by cattle, goats or poultry.

**DISCUSSION**

Field biologists are often able to describe the habitat of rare species in a detailed but still qualitative manner. In order to rate habitat quality more objectively and without the necessity of
extensive experience, a habitat quality index is a useful tool. This study shows that it can adequately explain differences between occupied and vacant patches. The index can be readily applied in the planning of conservation measures, by revealing promising sites with their strong and weak points and indicating the required management.

Table 2. Progressive proportion of the explained variation ($R^2$) in patch occupancy by *Melitaea cinxia* on 40 sites with increasing number of variables entered into the habitat quality index using logistic regression ($P<0.0001$ in all cases)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Progressive $R^2$</th>
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<tbody>
<tr>
<td>Standing dead vegetation</td>
<td>0.18</td>
</tr>
<tr>
<td>Acidity value</td>
<td>0.38</td>
</tr>
<tr>
<td>Structural diversity</td>
<td>0.46</td>
</tr>
<tr>
<td>Productivity value</td>
<td>0.67</td>
</tr>
<tr>
<td><em>Plantago</em> density</td>
<td>0.70</td>
</tr>
<tr>
<td>Open field border</td>
<td>0.73</td>
</tr>
</tbody>
</table>

Figure 2. Logistic regression curve of the probability of patch occupancy as a function of an habitat quality index ($R^2=0.611$, $P<0.0001$, $N=40$). Each point shows a running average for actual occupancy for two consecutive index points. Index values below 0 have been omitted, as they only represented vacant sites.

Figure 3. Average values of the habitat quality index for *Melitaea cinxia* for different types of habitat (top) and management (bottom) on 88 sites in the vicinity of Balen, Belgium. Differences were significant at $P<0.005$ (ANOVA, index values were normally distributed).
The present data indicate that abiotic conditions (moderately acid to calcareous soils with low to intermediate productivity) and small-scale diversity in vegetation structure are important aspects of habitat quality for *Melitaea cinxia*. These aspects have not been quantified earlier, although abiotic conditions have been described earlier in qualitative terms (Bink, 1992; Thomas & Lewington, 1991). The importance of standing dead vegetation for hibernation nests seems implied by Simcox & Thomas (1979) on the Isle of Wight, but hibernation apparently takes place mainly in low vegetation in Finland (M. Singer & M. Kuussaari, pers. comm.). It may be that the protection offered by standing dead vegetation is more important with the greater humidity and essentially snow-free winters of the oceanic climate in Western Europe.

Further validation of the habitat quality index for *Melitaea cinxia* is required with an independent data set, as the presented test was carried out with sites that were also used in the investigation to set up the index. Unfortunately, there are serious practical limitations to acquire an independent data set for such a rare species. Regional differences, *e.g.*, in climate, may preclude a test in other parts of its range. This calls for adaptive management with careful monitoring in the impending restoration programme. The challenge for future research clearly is to incorporate the index into existing metapopulation models, in order to achieve an integration of effects of habitat quality as well as area and isolation.

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**REFERENCES**