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Optimal timing of power line rights-of-ways management for the conservation of butterflies

ATTE KOMONEN,[1]* TERHI LENSU[2] and JANNE S. KOTIAHO[2,3]
[1]Department of Biological and Environmental Science, University of Jyväskylä, Jyväskylä, Finland, [2]Department of Biological and Environmental Science, Centre of Excellence in Evolutionary Research, University of Jyväskylä, Jyväskylä, Finland and [3]Natural History Museum, University of Jyväskylä, Jyväskylä, Finland

Abstract. 1. Habitat loss, fragmentation, and degradation are the main threats to biodiversity. Human activities also create new habitat types that might fulfil ecological requirements for a variety of species.

2. This study investigates whether the vegetation clearing (= shrub and tree cutting) on drained mire patches on power line rights-of-ways (ROWs) keep plant communities in an early successional stage and thus provide habitats for mire specialist and non-mire butterflies. It was further studied what would be the optimal clearing interval in terms of butterfly species richness and abundance.

3. The results show that tree height, especially the height of birch, increases linearly over the 7-year period following vegetation clearing. The average birch height had a significant negative relationship with the species richness of mire and non-mire butterflies.

4. The clearing interval had a significant curvilinear relationship with the abundance of both mire and non-mire butterflies, such that the highest abundances were documented two to four growing seasons after the clearing, which would hence be the ecologically optimal vegetation clearing cycle.

5. In general, vegetation management on power line ROWs enhance favourable conditions for butterflies and may maintain habitats for mire-dependent butterflies, even on drained mires.

Key words. Clearing, lepidoptera, mire, peatland, rights-of-way, vegetation management.

Introduction

The intensification of agriculture has drastically decreased the extent of traditional biotopes, such as meadows and semi-natural pastures (Pullin, 1995; Smallidge & Leopold, 1997; Croxton *et al.*, 2005; Bazelet & Samways, 2011), and the afforestation of former agricultural fields has further decreased the extent of open habitats (Stanton & Bills, 1996; Wall & Hytönen, 2005). Consequently, many butterfly populations all over the world have been collapsing (New *et al.*, 1995). In Finland, only 1% of the traditional biotopes remain in comparison with the situation 100 years ago (Salminen & Kekäläinen, 2000), and the overgrowing of meadows is related to the decline of 65% of the Finnish butterfly species (Somerma, 1997; Rassi *et al.*, 2010). Another important habitat type for butterflies is open peatlands (Pöyry, 2001; Rassi *et al.*, 2010). In many countries and across most biomes, peatlands cover significant proportions of land area: 11% in Canada, 14% in Indonesia, and 24% in Finland (Joosten, 2010).In Europe, however, c. 60% of the peatland area has been transformed into farmland, forest, or peat pits (Vasander *et al.*, 2003), and in Finland the percentage is even greater, totalling 80% in some regions (Raunio *et al.*, 2008). Peatlands are the main habitat type for 223 (4.5%) red-listed species and one habitat type among others for 420 red-listed species in Finland, including plants, invertebrates, and vertebrates (Rassi *et al.*, 2010). There is also increasing evidence that the transformation of peatlands has deteriorated and destroyed the habitat of mire butterflies and caused significant population declines and

*Correspondence: Atte Komonen, Department of Biological and Environmental Science, University of Jyväskylä, PO Box 35, 40014 Jyväskylä, Finland. E-mail: atte.komonen@jyu.fi

range contraction, especially in Southern Finland with the most extensive peatland drainage (Kontiokari, 1999; Kotiaho *et al*., 2005; Rassi *et al*., 2010; Mattila *et al*., 2011).

To offset the rampant biodiversity loss, habitat management and restoration have become topical tools in biodiversity conservation. Habitat creation and maintenance, however, are often by-products of anthropogenic activities that originally did not have biodiversity goals (Pywell *et al*., 1996; Morris *et al*., 2006). These activities may create complementary habitats for species for which the natural habitats have been largely degraded. For example, the original purpose of vegetation management on power line rights-of-ways (ROWs) is to guarantee reliable energy transfer, but at the same time management maintains early successional habitats for species which naturally dwell on meadows (Bazelet & Samways, 2011; Berg *et al*., 2011).

Power line ROWs are a major infrastructure habitat that covers large areas. In Finland, the land area covered by power line ROWs over 20 m wide is almost 50 000 hectares (A. Levula, pers. communication). Although the negative ecological effects of power lines, such as increased habitat fragmentation (Rich & Dobkin, 1994; Goosem & Marsh, 1997; Nellemann *et al*., 2003), edge effects (Kroodsma, 1984), and bird collisions with power lines (Martin & Shaw, 2010; Barrientos *et al*., 2011) have been extensively documented, the repeated removal of vegetation from ROWs is a disturbance agent that keeps plant communities in an early successional stage and provides habitats for a variety of species (Geibert, 1980; Askins, 1994; Smallidge *et al*., 1996; Yahner *et al*., 2001; King & Byers, 2002; Confer & Pascoe, 2003; Kuussaari *et al*., 2003; Forrester *et al*., 2005; Shine *et al*., 2006; Bazelet & Samways, 2011; Berg *et al*., 2011; Lensu *et al*., 2011). ROWs may also serve as movement corridors through otherwise unsuitable landscapes (Smallidge *et al*., 1996; Lehtomäki, 2006), although there is experimental evidence that electromagnetic radiation can influence the movement patterns of invertebrates (e.g. Jackson *et al*., 2011).

Most studies on power line ROW ecology have focused on mineral soils, such as meadows, whereas ROWs on mires have been neglected. Previously, however, it was shown that vegetation management has maintained species richness and abundance of mire butterflies on drained mires on ROWs (Lensu *et al*., 2011). Relatively few studies have investigated the effect of management interval on biological diversity. According to management guidelines, vegetation on power line ROWs in Finland is managed by mechanical clearing with an interval of every 6 years (Vuorinen, 2001). In the present study, we selected mire patches on power line ROWs to study the abundance and species richness of mire specialist and non-mire butterflies. More specifically, we analysed the relationships between the time from the last vegetation clearing, vegetation succession (height and density of trees) and butterfly species richness and abundance, to determine the optimal ROW management interval for the conservation of butterflies.

Methods

Study sites

This study was carried out on a power line ROW in Central Finland (62°N, 26°E) in the middle boreal vegetation zone. The 220 kV power line ROW is 65 m wide and runs about 70 km from south to north from Kuhmoinen to Karstula, across a mosaic of peatlands and coniferous forests on mineral soils; there is very little farmland in the region. The power line ROW was established some 50 years ago, and since then it has been kept open by mechanical clearing. The studied mires on ROWs had been ditched after the power line construction, and based on the vegetation study on the same sites (Hiltula *et al*., 2005), these were transitional mires, that is they still had characteristic pine mire vegetation and a peat layer over 50 cm thick. The drained ROW mires had less cover of *Sphagnum* moss, and larger cover and species richness of forest species than natural mires (Hiltula *et al*., 2005). A total of 15 drained mires on the power line ROW were chosen as study sites for butterfly monitoring. The distance between the study sites was on average 1.5 km (range = 500 m–18 km). The study mires were always separated by at least one mineral soil ridge.

Butterfly monitoring and environmental variables

Butterflies were monitored on each site in 2004, 2006, 2007, and 2008. One of the sites was cleared during the winter 1996–1997, seven during 1997–1998, one during 2002–2003, and six during 2003–2004. Thus, in the first monitoring occasion in the summer of 2004, the sites differed in terms of the time from the last clearing, varying from one to eight growing seasons. All the sites that had been cleared during 1996–1997 or 1997–1998 were cleared again during winter 2004–2005 or 2005–2006. As it was not possible to control the vegetation management schedule, the initial data lacked some clearing intervals; thus, two additional sites were selected and these were monitored only in 2007 and 2008. Finally, the data included 17 sites. It should be noted that the data are such that the same sites were sampled several times (Appendix 1). What is important for this study, however, is that each of the site-year combinations is unique. Differences between years (e.g. weather) could cause spurious correlations between clearing cycle and species richness or abundance of butterflies. In this study, we tried to minimise this problem by sampling at least four different clearing intervals in each study year, and sites were visited in random order over years.

The line transect sampling method (Pollard & Yates, 1993) was used for butterfly monitoring. One 250-m butterfly transect, starting from a random point, was established on each study site. Because of the small area of ROW mires, transects were generally zigzag-shaped and always at least 10 m from the ROW edge. Butterfly monitoring was carried out during June and July, between 10 a.m. and 5 p.m., and each site was visited in 5–10-day intervals and included 3–8 (mean = 6.4, SE = 0.17, median = 7) monitoring occasions per site per year depending on weather conditions. All mire-dependent butterflies in Finland overwinter as larvae, so their flight period in Central Finland is from June to July (Marttila *et al.*, 2001); thus, it is unlikely that we missed any of these species. Although the non-mire species overwinter as larvae, pupa or adults, they all are in flight in June or July. On sunny days the temperature had to be higher than 13 °C, and on cloudy days higher than 17 °C; the temperature was measured 1 m above the ground. Monitoring was not carried out when wind strength increased to six, estimated on the Beaufort scale. Transects were walked by two persons at constant speed, and observations were made from an area of 5 m × 5 m in front of the observers; monitoring by two persons ensured that while one was taking notes, or chasing or identifying a butterfly individual (caught by a sweeping net, if necessary), the other was able to continue monitoring. Because the number of visits varied, the number of butterfly species and individuals per visit were used in the analyses. Following Marttila *et al.* (2001), butterflies were classified as non-mire species or as mire-dependent species, that is species that feed on plants that predominantly grow on mires.

The height and number of trees (>50 cm in height) were measured from two 5 m × 5 m plots, which were located on the butterfly transects, about 75 m from both ends. Only the three most numerous tree species, Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*), and Downy birch (*Betula pubescens*), were included in analyses.

Data analysis

The relationships between the time from last clearing (one to eight growing seasons), the relationship between species richness or abundance of mire and non-mire butterflies, and the average tree height or density were analysed using univariate linear regression. We used univariate regression because of the collinearity between predictor variables. Because the relationship between the abundance and the time from last clearing remained curvilinear after ln-transformation, abundance data were reanalysed using quadratic regression, followed by an *F*-test to test if the second-order term explains significantly more variation than the linear model. *F*-statistic was calculated as $\text{d.f.}_j \times (r^2_j - r^2_i)/(1 - r^2_j)$, where r^2_j is the variance explained by the quadratic term and r^2_i is the variance explained by the linear term. *F*-statistic has j degrees of freedom in the numerator and $n - j - 1$ degrees of freedom in the denominator. Residuals appeared homoskedastic and without significant outliers, except for some positive heteroskedasticity in the analyses of birch height vs. mire species richness or their abundance; however, this should only influence the error variances of parameter estimates (which we do not report), not the conclusions. All analyses were conducted with PASW Statistics version 18.0 (IBM Company, Quarry Bay, Hong Kong).

Results

Overall, 11 324 individuals of 35 butterfly species were recorded, of which 1940 and 8, respectively, were mire-dependent species (Appendix 2). Pine was more abundant [mean density (median) ± SE = 3.6 (2.8) ± 0.3] than birch [3.3 (0.8) ± 0.8] or spruce [1.4 (0.5) ± 0.3)]. The general trend was that tree height increased with the time from last vegetation clearing. The time from last clearing (1–8 growing seasons) had a positive linear relationship with the height of birch and pine ($F_{1,30} = 44.7$, $P = 0.000$, $r^2 = 0.60$ and $F_{1,62} = 41.4$, $P = 0.000$, $r^2 = 0.40$, respectively), but not with the height of spruce ($F_{1,44} < 3.3$, $P = 0.08$) or the densities of any of the tree species ($F_{1,62} < 3.0$, $P > 0.09$) (degrees of freedom differ between density and height analyses because zero densities were included, whereas zero heights were excluded as meaningless).

The height of birches had a significantly negative relationship with the species richness of mire and non-mire butterflies, and the height of pines had a significantly negative relationship with the abundance of non-mire butterflies (Fig. 1). There was also a tendency ($P = 0.05$–0.06) for the height of birches to be negatively related to the abundances of mire and non-mire butterflies, and the height of pines was negatively related to the abundances of mire butterflies.

The time from last clearing was not related to the species richness of mire butterflies, but had a significantly negative relationship with the non-mire species richness (Fig. 2). The time from last clearing had a curvilinear relationship with the abundance of both mire and non-mire butterflies (Fig. 2), such that the highest abundances were reached two to four growing seasons after the clearing. The second-order term explained significant amounts of additional variation in both analyses (mire spp: $F_{2,61} = 10.81$, $P < 0.001$; non-mire spp: $F_{2,61} = 23.82$, $P < 0.001$). Of the eight mire-dependent species, the abundances of *Boloria aquilonaris* ($F_{2,61} = 4.7$, $P = 0.013$, $r^2 = 0.13$), *B. eunomia* ($F_{2,61} = 6.4$, $P = 0.003$, $r^2 = 0.17$), and *Colias palaeno* ($F_{2,61} = 6.5$, $P = 0.003$, $r^2 = 0.18$) had a significant relationship with the time from last clearing; however, the second-order term explained significant amounts of additional variation only for *B. eunomia* ($F_{2,61} = 8.82$, $P < 0.001$).

Discussion

The results demonstrate that the ecologically optimal clearing interval of power line ROWs for mire and non-mire butterflies is roughly 2–4 years. This is particularly true considering the abundance of both species groups and species richness of non-mire butterflies. These results

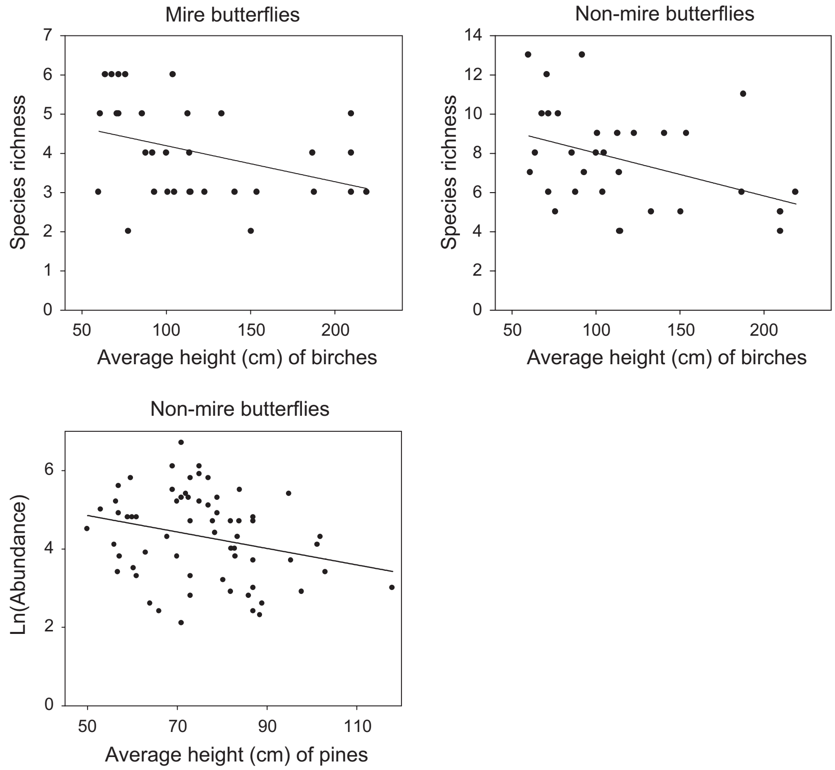

Fig. 1. The significant relationships between the average height of birches or pine and the species richness or abundance of mire and non-mire butterflies. Mire species richness – birch height: $F_{1,30} = 4.6$, $P = 0.04$, $r^2 = 0.13$; Non-mire species richness – birch height: $F_{1,30} = 6.3$, $P = 0.02$, $r^2 = 0.17$; Non-mire species abundance – pine height: $F_{1,62} = 4.4$, $P = 0.04$, $r^2 = 0.07$. In the panel for Species richness of mire butterflies, three overlapping symbol couples have been slightly moved along x-axis.

are in accordance with the studies on meadow butterflies on power line ROWs (Kuussaari *et al*., 2003). The abundance of butterflies started to decline already four growing seasons after the clearing, and remained low during the first season after the clearing until population growth and possibly immigration remedied the situation. During the low-density years in the beginning and at the end of the clearing cycle, any stochastic and deterministic factor can greatly increase the extinction probability of the small populations on ROW habitats. According to the ROW management guidelines (Vuorinen, 2001), the clearing interval in Finland is 6 years, but this is likely to be the minimum interval due to the economic costs associated with the clearing. Although it is unrealistic to shorten the clearing interval to 1–3 years, and too frequent clearing could negatively influence butterflies and their host plants (Kuussaari *et al*., 2003), 1–2-year shortening would still benefit butterflies. Shorter clearing intervals could also be applied in sites or regions where butterfly conservation is considered an important management objective.

One should note that due to practical reasons our sampling was not optimal in the sense that not all the clearing intervals were equally represented every sampling year, that is year and clearing interval cannot be fully separated from each other. Although our results about the influence of clearing interval on butterflies are in accordance with other studies in power line ROWs in Finland (Kuussaari *et al*., 2003), the year-effect might have influenced the patterns to some extent. Future studies should investigate the influence of clearing interval and method (e.g. removing vs. retaining residues) and their interactions in different habitats using field experiments.

One important underlying ecological factor affecting the species richness and abundance of butterflies in early successional habitats is vegetation height and density. On power line ROWs, vegetation height and density have been shown to negatively influence meadow butterflies (Kuussaari *et al*., 2003) and grasshoppers (Bazelet & Samways, 2011). ROW management, however, may increase the density of plants, which are food sources for larvae or nectar sources for adult butterflies (Forrester *et al*., 2005). Our results support these observations by demonstrating that in mires the height of birch trees in particular negatively influenced mire and non-mire butterflies. Shortening the clearing interval not only reduces shading but also decreases the amount of clearing residues, which benefits butterflies at least on ROW meadows (Kuussaari *et al*., 2003). Because tree growth on drained peatland is generally slower than on mineral soil forest land, it is unlikely that a single clearing interval would be optimal for all habitat types on

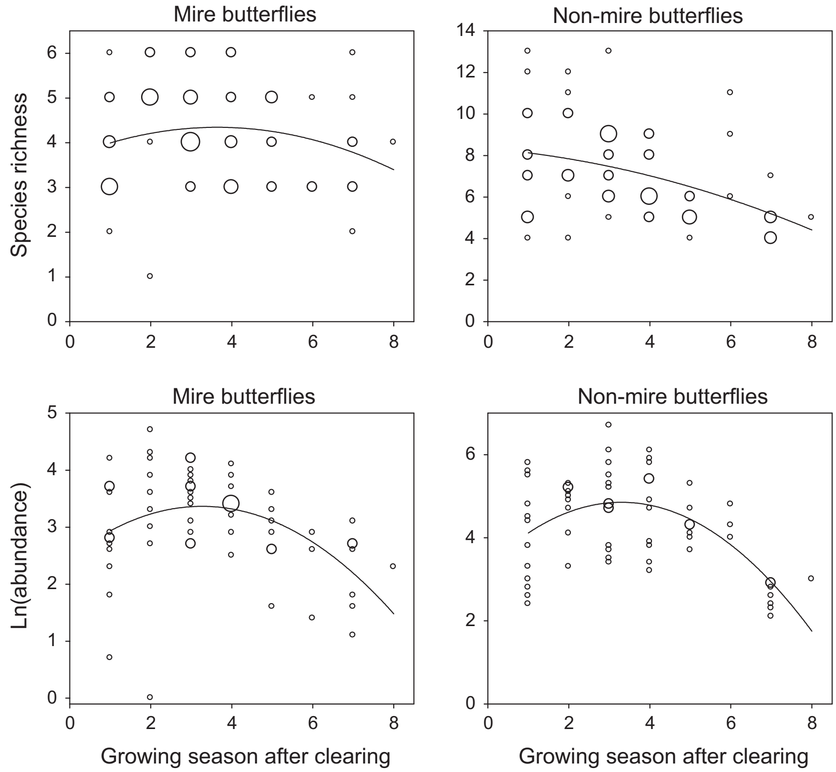

Fig. 2. The relationship between the stage of the clearing cycle and the species richness or abundance of mire and non-mire butterflies. The summary statistics of the quadratic regression analyses; Mire species richness: $F_{2,61}$ = 1.05, P = 0.36, r^2 = 0.03; Mire species abundance: $F_{2,61}$ = 7.92, P = 0.001, r^2 = 0.21; Non-mire species richness: $F_{2,61}$ = 6.24, P = 0.003, r^2 = 0.17; Non-mire species abundance: $F_{2,61}$ = 17.02, P = 0.001, r^2 = 0.36. Symbol size indicates the number (1–6) of overlapping points.

ROWs; particularly fertile sites with plenty of broadleaved trees should be cleared more often than infertile sites. Despite somewhat slower tree growth on drained mires than on mineral soils, previous studies have shown that drained peatlands bordering power line ROWs have attained dense tree stock and canopy cover, which negatively influence the species richness of mire butterflies (Lensu *et al.*, 2011). Because most of the mires surrounding ROWs have also been drained, but not kept open, there is very little rescue effect from the surrounding areas.

Because of the dynamic nature of early successional habitats, site protection alone is seldom a successful butterfly conservation strategy, and conservation plans must include some form of active management (Warren, 1993a,b; Morris *et al.*, 1994; New *et al.*, 1995; Smallidge & Leopold, 1997). The present study supports previous studies in that the vegetation management of power line ROWs creates and maintains habitat for many butterfly species, including rare and declining ones (Ravenscroft, 1994; Klemetti & Wahlberg, 1997; Heliölä *et al.*, 2000; Kuussaari *et al.*, 2003; Berg *et al.*, 2011). One should remember, however, that unlike many meadows and semi-natural pastures, which are maintained only by regular disturbances, natural, open peatlands are not transient habitats. As many intact mires occur patchily, the vegetation management on ROWs may increase their quality as dispersal corridors (Haddad, 2000), and thus promote genetic exchange and enhance population viability. Vegetation management for mire-dependent butterflies is important, not only in the ROW mires but also in the mineral soil ridges in-between, because even subtle habitat boundaries can act as dispersal barriers for butterflies (Ries & Debinski, 2001).

Although the present study identifies some positive aspects of power line ROWs, one should keep in mind that in pristine areas, ROW establishment always alters natural habitats. The ecological consequences, however, greatly depend on the original habitat type. In forests, the difference between the original and the cleared ROW habitat is the greatest, whereas in meadows or open peatlands the difference is much smaller (e.g. Berg *et al.*, 2011; Lensu *et al.*, 2011). In fact, although vegetation clearing on ROWs is an anthropogenic disturbance, for butterflies it seems to counterbalance the negative effects of the original disturbance, that is the drainage of pristine mires. The realistic management goal of ROWs is to try to increase the biodiversity benefits by managing ROWs as integral parts of broader ecological networks, comprising patches of natural and complementary habitats and corridors (Bazelet & Samways, 2011; Berg *et al.*, 2011).

Conclusions

This study shows that regularly cleared and drained mires on power line ROWs can be viewed as habitat patches for mire-dependent butterflies. The results also suggest that the optimal vegetation clearing interval on mires on ROWs is 2–4 years, but shortening the current 6-year interval by a year or two would already enhance habitat quality for all butterflies. The need for vegetation management and the optimal clearing interval are also likely to vary because vegetation characteristics vary in different sites. Furthermore, ROW management could aim at specific biodiversity goals in regions where they can complement existing natural habitats or increase habitat connectivity. More broadly, the clearing interval can be seen as a way to intentionally influence the disturbance regime to obtain biodiversity benefits. Similar considerations have been – and should be – applied to other situations as well, such as the management of road verges or meadows.

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Appendix 1

The vegetation clearing and butterfly monitoring schedule during years 2004, 2006, 2007, and 2008. 'Clearing' indicates the initial clearing year; and 'Time from clearing' the number of growing seasons since the preceding clearing. Sites that were initially cleared during 1996–1998 were cleared again 2004–2005 or 2005–2006. Sites 16 and 17 were included to cover some clearing intervals that were lacking from the data

		Time from clearing			
Sites	Clearing	2004	2006	2007	2008
1	2003–2004	1	3	4	5
2	2003–2004	1	3	4	5
3	2003–2004	1	3	4	5
4	2003–2004	1	3	4	5
5	2003–2004	1	3	4	5
6	2003–2004	1	3	4	5
7	2002–2003	2	4	5	6
8	1996–1997	8	2	3	4
9	1997–1998	7	2	3	4
10	1997–1998	7	2	3	4
11	1997–1998	7	2	3	4
12	1997–1998	7	1	2	3
13	1997–1998	7	1	2	3
14	1997–1998	7	1	2	3
15	1997–1998	7	1	2	3
16	2001–2002			6	1
17	2001–2002			6	1

Appendix 2

List of the mire and non-mire butterfly species recorded from the power line ROWs 2004, 2006, 2007, and 2008. Abundance = mean ± SE number of individuals per visit (n = 64); occurrence = the number of visits a given species was recorded

Butterflies	Abundance	Occurrence
Mire species		
Pyrgus centaureae	0.06 ± 0.04	3
Colias palaeno	5.89 ± 0.55	62
Boloria eunomia	9.73 ± 1.00	60
Boloria freija	0.02 ± 0.02	1
Boloria frigga	0.56 ± 0.15	19
Boloria aquilonaris	8.91 ± 1.33	57
Coenonympha tullia	1.02 ± 0.21	27
Oeneis jutta	2.08 ± 0.33	36
Other species		
Thymelicus lineola	0.78 ± 0.19	21
Ochlodes sylvanus	0.09 ± 0.05	4
Aporia crataegi	0.28 ± 0.07	15
Pieris napi	0.03 ± 0.02	2
Gonepteryx rhamni	0.03 ± 0.03	1
Callophrys rubi	0.41 ± 0.08	21
Heodes virgaureae	0.08 ± 0.06	2
Palaeochrysophanus hippothoe	0.05 ± 0.04	2
Celastrina argiolus	0.05 ± 0.03	3
Plebejus argus	54.69 ± 10.71	62
Lycaeides idas	25.33 ± 4.50	56
Vacciniina optilete	21.19 ± 2.17	63
Cyaniris semiargus	0.08 ± 0.03	5
Agrodiaetus amandus	0.08 ± 0.04	4
Limenitis populi	0.02 ± 0.02	1
Inachis io	0.02 ± 0.02	1
Aglais urticae	0.08 ± 0.04	4
Speyeria aglaja	0.30 ± 0.12	10
Fabriciana adippe	0.11 ± 0.07	4
Brenthis ino	8.61 ± 1.54	54
Clossiana selene	1.22 ± 0.37	19
Clossiana euphrosyne	14.69 ± 1.72	63
Mellicta athalia	0.14 ± 0.06	7
Erebia ligea	0.30 ± 0.10	11
Aphantopus hyperantus	0.59 ± 0.19	13
Lasiommata maera	0.13 ± 0.05	7
Lasiommata petropolitana	0.03 ± 0.02	2