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REVIEW PAPER

Land management impacts on European butterflies of conservation concern: a review

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Abstract Recent land use changes, namely the intensification of agriculture and forestry as well as the abandonment of traditional grassland management methods, have resulted in the decline of butterfly diversity in Europe. Appropriate management of butterfly habitats is thus required in order to reverse this negative trend. The aim of our study was to review the available literary information concerning the effects of various types of management on European butterflies of conservation concern, and to provide practical recommendations for the management of butterfly habitats. Since vegetation succession is a major threat to butterfly populations, there is a need for activities to suppress this process. Extensive grazing and rotational mowing, which imitate the traditional way of meadow use, appear to be the most suitable management in this respect. Both grazing and mowing should optimally be of low intensity and follow a mosaic design, with different land fragments being successively used at different times. Habitat disturbance through trampling, either associated with grazing or various sporting activities (hiking, biking, horse riding), or through occasional small-area burning, also prove to be beneficial for many butterflies. In the case of woodland species, maintaining open habitats within forests (glades, clearings, wide road verges) and thinning forest stands is recommended. Among the unfavourable management activities identified, the most harmful are afforestation of open lands and drainage works. Therefore, such activities must be stopped at butterfly sites in order to ensure the effective conservation of species of conservation concern.

Keywords Agriculture · Biodiversity · Forestry · Habitat management · Land use · Species conservation

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Introduction

European landscapes and their use by agriculture and forestry have been undergoing considerable changes in recent decades (Reidsma et al. 2006). These changes have typically led to the cessation of the traditional use of semi-natural habitats, causing either the complete abandonment of land or the introduction of intensive agriculture and forestry (Balmer and Erhardt 2000; Young et al. 2005). Both processes are considered prominent threats to biodiversity in Europe (Morris 2000; Benton et al. 2003; Saarinen and Jantunen 2005; Young et al. 2005). They have led to the destruction of many habitats as well as to the deterioration of the quality of the remaining habitat fragments (Begon et al. 2006). They have also affected the spatial structure of habitats, usually increasing their fragmentation, which threatens the survival of numerous species (Krauss et al. 2005; Pöyry 2007). One of the main groups of organisms negatively affected by these processes are butterflies (Öckinger and Smith 2006; Wenzel et al. 2006; Kőrösi et al. 2012).

On the other hand, through proper conservation-oriented land management we are able to enhance the chances of butterfly survival even in severely altered and fragmented landscapes. Management activities may improve the quality of habitat patches of individual species (Kruess and

Tscharntke 2002; Sawchik et al. 2003; Wenzel et al. 2006). This is particularly true for many endangered butterflies, which have suffered from long-term land abandonment leading to meadow succession and subsequent penetration by shrubs and trees (Morris 2000; Hula et al. 2004; Pöyry et al. 2006).

However, high quality habitat patches do not always foster species occurrence. Even if a patch fulfils all of the species requirements, individuals will not occur there as long as the patch is too isolated and far beyond their ability to disperse (Schtickzelle et al. 2006). Therefore, it is important to maintain well-connected networks of habitat patches (Hanski et al. 1994, 1995; Thomas et al. 2001; Schtickzelle and Baguette 2003; Öckinger and Smith 2007). Again, proper land management may help in this respect by facilitating butterfly dispersal and thus reducing the impact of fragmentation of their habitat patches. This can be achieved either directly through creating corridors and stepping stone habitats (Haddad 1999; Skórka et al. 2013) or indirectly through promoting dispersal behaviour in butterflies (Begon et al. 2006). Dispersal distance and individual willingness to emigrate are key traits for the persistence of populations in fragmented landscapes (Schtickzelle et al. 2005; Fric et al. 2010; Hambäck et al. 2010; Zimmermann et al. 2011).

In our paper we have compiled and reviewed available information regarding the effects of different small-scale land management practices on endangered European butterfly species. By doing so, we aim to drawing general conclusions about their relative role, either positive or negative, in shaping butterfly communities. We also attempt to provide conservation recommendations based on the outcome of our review.

We focused on management activities applicable at the small-scale of nature reserves or Natura 2000 sites, because we believe that such a scale is the most relevant for successful butterfly conservation. First of all, populations of most European butterflies typically exist in relatively small local populations expanding over a few to few tens of hectares (Warren 1992). Apart from this, small-scale conservation actions, following the principle of "think globally, act locally", proved to be more effective for butterflies (cf. Thomas et al. 2011), although obviously their applicability (or preventing in the case of unfavourable management) is affected by large-scale environmental policies.

Review approach

We conducted a comprehensive search for research papers dealing with the effects of various types of land management on butterflies in Europe, using the Web-of-Knowledge (http://apps.webofknowledge.com/) and Scopus (http://www.scopus.com/) databases. Wherever possible, we additionally supplemented the information gathered in this way with the material from relevant 'grey literature' known to us.

We focused our review primarily on species of conservation concern that are listed in the European Red List of Butterflies, including those classified as Near Threatened (van Swaay et al. 2010). There is a clear discrepancy in the scientific literature dealing with the conservation of European butterflies, with many papers from Northern and Western Europe, and much lower numbers of those from other parts of the continent. We partly mitigated this problem by including a large bulk of local literature or even unpublished reports, mostly from Central and Eastern Europe. Nevertheless, as many local publications are not easily accessible and/or published in national languages unknown to us, some biases in geographical coverage of our review still remain. In particular, the amount of information we have managed to collect for butterflies with distribution ranges restricted to the Alpine and Mediterranean regions is not as large as that available for species from other regions. However, we strongly believe that the material we have gathered is extensive and comprehensive enough (>100 papers representing almost all European countries) to allow drawing general conclusions about the impacts of various types of habitat management.

We classified the management types into two categories: favourable or unfavourable for butterflies. Their impacts on butterflies of conservation concern have been summarised in Tables 1 and 2. In turn, Fig. 1 presents the relative importance of different management types for butterflies. Below, we discuss their effects in a systematic way.

Favourable management

Rotational mowing

One of the most effective ways for the conservation for endangered butterflies through meadow management is rotational mosaic mowing, usually complemented by extensive grazing as described below (Saarinen and Jantunen 2005; Farruggia et al. 2012). Rotational mosaic mowing implies successive mowing of different meadow fragments (Morris and Rispin 1987; Saarinen and Jantunen 2005; Novák et al. 2007; Gaisler et al. 2011). This mowing method resembles traditional meadow management (Pöyry 2007), the abandonment of which has led to the decline of numerous meadow specialists, including the endangered *Colias myrmidone* (Esper, 1781) (Konvička et al. 2008a) or charismatic large blue butterflies of the genus *Maculinea* (=*Phengaris*), which are flagships of grassland conservation in Europe (Thomas et al. 2009). The future survival of the aforementioned species is dependent on the application

Table 1 Positive effects of habitat management on European butterflies of conservation concern documented in the literature

Species	Status	Favourable management type					
		Rotational mowing	Extensive grazing	Trampling	Occasional burning	Fallowing	Maintenance of sparse forest stands
Archon apollinus	NT		80				
Aricia anteros	NT					72	
Boloria chariclea	NT	9					
Boloria titania	NT	13, 73	13				
Carcharodus flocciferus	NT	24, 4	24				
Carcharodus lavatherae	NT	86, 4	14, 86				
Chazara briseis	NT		35, 38, 39	26, 35			
Coenonympha hero	VU	11		10			
Coenonympha oedippus	EN	62, 69	17				
Coenonympha orientalis	VU						50
Coenonympha phryne	CR	85	86				
Coenonympha tullia	VU	94	85, 94		20	94	
Colias chrysotheme	VU		48	85, 4			
Colias hecla	NT	85	85				
Colias myrmidone	EN	45	45, 78, 90				
Cupido decoloratus	NT			4, 5			
Erebia christi	VU		52				
Erebia claudina	NT		85				85
Erebia epistygne	NT		87				87
Erebia flavofasciata	NT		15				50
Erebia sudetica	VU						4, 47, 51
Euphydryas desfontainii	NT		63, 63	64			
Euphydryas iduna	NT						49
Euphydryas maturna	VU						1, 19, 29, 93
Gonepteryx cleobule	VU						50
Gonepteryx maderensis	EN						85
Hipparchia bacchus	VU					50	
Hipparchia fagi	NT		66	4	57		
Hipparchia hermione	NT		4		4		4, 66
Hipparchia statilinus	NT		4	65	4		
Hipparchia tilosi	VU						50
Iolana iolas	NT		58	68	58		
Leptidea morsei	NT						4, 18, 34
Lopinga achine	VU		4				6, 7, 46, 77
Lycaena helle	EN	4, 28, 30	3, 30, 31	75			
Maniola halicarnassus	NT	50					
Melitaea aurelia	NT	4	4, 27	27, 40			
Melitaea britomartis	NT		4, 12				
Muschampia cribrellum	NT	41	22				
Pararge xiphia	EN		71				37
Parnassius apollo	NT		8, 70	70			
Parnassius mnemosyne	NT						43, 55, 84
Parnassius phoebus	NT	85					
Phengaris arion	EN	74, 76	76, 82	82			
Phengaris nausithous	NT	32, 36, 59	59	44	60		
Phengaris teleius	VU	36, 83	32, 59, 96, 97	44	60		

Table 1 continued

Species	Status	Favourable management type					
		Rotational mowing	Extensive grazing	Trampling	Occasional burning	Fallowing	Maintenance of sparse forest stands
Plebejus dardanus	NT			50			
Plebejus pylaon	NT	58	4, 58		58		
Plebejus trappi	NT		85				
Plebejus zullichi	EN					2	
Polyommatus eros	NT		95				
Polyommatus galloi	VU		23				
Polyommatus humedasae	EN			87, 89	87		
Polyommatus nephohiptamenos	NT	85					85
Polyommatus damon	NT	4	25	79			
Polyommatus dorylas	NT		86				
Polyommatus nivescens	NT	89					
Polyommatus orphicus	VU				42		
Pseudochazara amymone	VU	16	16				92
Pseudochazara cingovskii	CR			92			
Pseudochazara euxina	EN		50				
Pseudochazara orestes	VU						85
Pseudophilotes panoptes	NT		61, 68	61			
Pseudophilotes vicrama	NT		4, 31, 86	4			
Pyrgus cirsii	VU	33	85				
Thymelicus acteon	NT	4, 81				56	
Tomares nogelii	VU	21					85
Turanana taygetica	EN			89		89	
Zerynthia cerisy	NT	53, 54					

The species conservation status follows the European Red List of Butterflies (van Swaay et al. 2010): *CR* critically endangered, *EN* endangered, *VU* vulnerable, *NT* near threatened. Numbers in the table refer to the papers reporting the effects: (1) AOPK (2011); (2) Barea-Azcón et al. (2014); (3) Bauerfeind et al. (2009); (4) Beneš et al. (2002); (5) Beneš et al. (2003); (6) Bergman (1999); (7) Bergman (2001); (8) Bohlin et al. (2008); (9) Britten and Brussard (1992); (10) Cassel et al. (2001); (11) Cassel et al. (2008); (12) Cerrato et al. (2014); (13) Cozzi et al. (2008); (14) Coutsis and Ghavalás (2001); (15) Cupedo (2000); (16) Cuvelier and Mølgaard (2015); (17) Čelik et al. (2009); (18) Čelik (2013); (19) Čizek and Konvička (2005); (20) Dennis and Eales (1997); (21) Dincă et al. (2009); (22) Dincă et al. (2010); (23) Dinca et al. (2013); (24) Dolek and Geyer (1997); (25) Dolek and Geyer (2002); (26) Dover and Settele (2009); (27) Eichel and Fartmann (2008); (28) Fischer et al. (1999); (29) Freese et al. (2006); (30) Goffart et al. (2010); (31) Grill and Cleary (2003); (32) Grill et al. (2008); (33) Guillaumin (1972); (34) Höttinger (2004); (35) Johannesen et al. (1997); (36) Johst et al. (2006); (37) Jones and Lace (1992); (38) Kadlec et al. (2009); (39) Kadlec et al. (2010); (40) Kleyer et al. (2007); (41) Kolev (2003); (42) Kolev (2005); (43) Konvička and Kuras (1999); (44) Konvička et al. (2005); (45) Konvička et al. (2008a); (46) Konvička et al. (2008b); (47) Konvička et al. (2014); (48) Korb (1994); (49) Kozlov and Kullberg (2008); (50) Kudrna et al. (2015); (51) Kuras et al. (2003); (52) Leigheb et al. (1998); (53) Lelo and Spasojević (2012); (54) Lelo (2000); (55) Luoto et al. (2001); (56) Louy et al. (2007); (57) Möllenbeck et al. (2009); (58) Munguira and Martín (1993); (59) Novák et al. (2007); (60) Nowicki et al. (2015); (61) Obregón et al. (2014); (62) Örvössy et al. (2013); (63) Pennekamp et al. (2013); (64) Pennekamp et al. (2014); (65) Pinzari (2009); (66) Pinzari and Sbordoni (2013); (67) Rabasa et al. (2007); (68) Settele et al. (2008);(69) Settele (2010); (70) Schmeller et al. (2011); (71) Shreeve and Smith (1992); (72) Schurian (1995); (73) Schweiger et al. (2008); (74) Sielezniew and Rutkowski (2012); (75) Skórka et al. (2007); (76) Spitzer et al. (2009); (77) Streitberger et al. (2012); (78) Szentirmai et al. (2014); (79) Šlancarová et al. (2012); (80) Šlancarová et al. (2015); (81) Thomas et al. (1992); (82) Thomas (1995); (83) Thomas et al. (2009); (84) Välimäki and Itämies (2003); (85) van Swaay and Warren (1999); (86) van Swaay (2002); (87) van Swaay et al. (2010); (88) van Swaay et al. (2012); (89) van Swaay et al. (2011); (90) Verovnik et al. (2011); (91) Verovnik et al. (2013); (92) Verovnik et al. (2014); (93) Vrabec (2001); (94) Weking et al. (2013); (95) Wiemers et al. (2010); (96) Witek et al. (2010); (97) Witek et al. (2011)

of meadow management, which should follow the principles of rotational mosaic mowing. These principles involve (i) relatively low mowing intensity, with a single fragment being mown no more than once per year, and (ii) mowing different fragments at different times in order to ensure heterogeneous turf height within meadows (Morris 2000). A higher mowing frequency may be beneficial for xerophilous species, which prefer short vegetation, e.g.,

Table 2 Negative effects of habitat management on European butterflies of conservation concern documented in the literature

Species	Status	Unfavourable management type			
		Afforestation	Drainage	Intensive agriculture	Intensive forestry
Aricia anteros	NT			30, 70	
Boloria chariclea	NT			71	
Boloria improba	EN			80	
Boloria polaris	VU			47	
Boloria titania	NT		12		
Carcharodus flocciferus	NT			4, 20, 45	
Carcharodus lavatherae	NT	4, 81		81	
Chazara briseis	NT	31		34, 66	
Coenonympha hero	VU	10		9	
Coenonympha oedippus	EN	65, 79	56, 65, 79	13, 56	
Coenonympha phryne	CR	80		80, 85	
Coenonympha tullia	VU	16, 61, 90	16, 32, 33		
Colias chrysotheme	VU	4, 80		80	
Colias myrmidone	EN	41, 74		23, 41	
Cupido decoloratus	NT	4			
Erebia christi	VU				84
Erebia claudina	NT			80	
Erebia epistygne	NT			15	
Erebia sudetica	VU	43, 48		43	
Euchloe bazae	VU			80	
Euphydryas desfontainii	NT		57, 58	58	
Euphydryas iduna	NT	46	46		
Euphydryas maturna	VU	24, 40, 88		1, 80, 88	
Gonepteryx cleobule	VU			47	
Gonepteryx maderensis	EN		80		80
Hipparchia bacchus	VU			47	
Hipparchia fagi	NT	53, 60, 68		53	
Hipparchia hermione	NT	4, 60			
Hipparchia leighebi	NT			47, 82	
Hipparchia sbordonii	NT			82	
Hipparchia statilinus	NT	59		4, 59	
Iolana iolas	NT	62		62, 63	
Leptidea morsei	NT	14, 29		14, 80	
Lopinga achine	VU	5, 42		36, 73	
Lycaena helle	EN	3, 27	28	3, 25, 27	
Melitaea aurelia	NT	21, 64		45	
Melitaea britomartis	NT	11, 44, 45	11	4	
Muschampia cribrellum	NT			18, 37	
Oeneis norna	NT		6		
Pararge xiphia	EN	69		69	
Parnassius apollo	NT	17, 50, 55			50
Parnassius mnemosyne	NT	39, 78			39, 51, 52
Parnassius phoebus	NT	80		80	
Phengaris arion	EN		8	72	
Phengaris nausithous	NT		22, 35	91	
Phengaris teleius	VU		22, 35	91	
Pieris cheiranthi	EN		80		

Table 2 continued

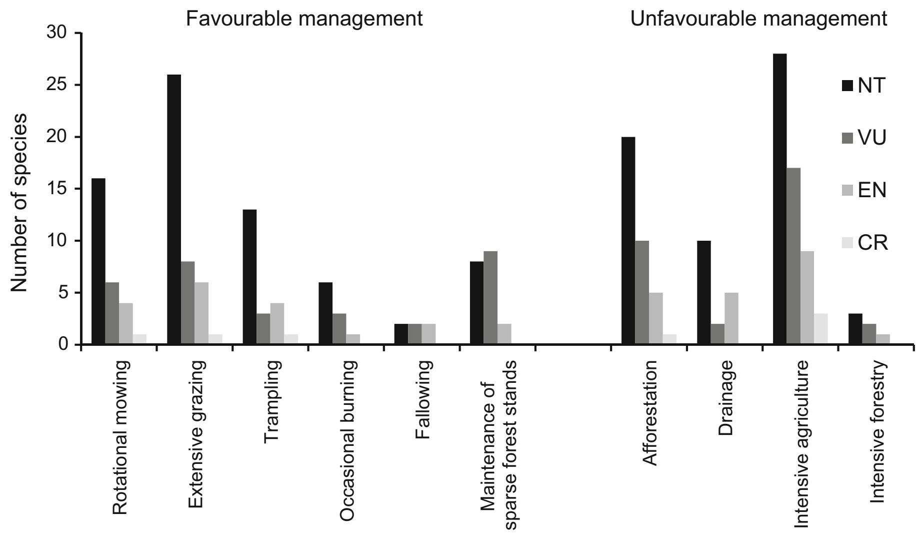
Species	Status	Unfavourable management type			
		Afforestation	Drainage	Intensive agriculture	Intensive forestry
Pieris wollastoni	CR			82	
Plebejus dardanus	NT			47	
Plebejus pylaon	NT			53	
Plebejus trappi	NT		80	80	
Plebejus zullichi	EN			53	
Polyommatus eros	NT	89		89	
Polyommatus galloi	VU			19	
Polyommatus golgus	VU			47, 89	
Polyommatus humedasae	EN	80			
Polyommatus nephohiptamenos	NT		80	80	
Polyommatus damon	NT	4, 75	4	75	
Polyommatus dorylas	NT	80			
Polyommatus nivescens	NT	82			
Polyommatus orphicus	VU	38		38	
Polyommatus violetae	VU	47		47	
Pseudochazara amymone	VU			87	
Pseudochazara cingovskii	CR			87	
Pseudochazara euxina	EN			47	
Pseudophilotes panoptes	NT	55		55, 82	
Pseudophilotes vicrama	NT	4, 26			
Pyrgus cirsii	VU	80		80	
Thymelicus acteon	NT			49, 77, 76	4
Tomares nogelii	VU	17, 80		17	80
Turanana taygetica	EN			82	
Zegris eupheme	NT			47	
Zerynthia cerisy	NT		2		

The species conservation status follows the European Red List of Butterflies (van Swaay et al. 2010): *CR* critically endangered, *EN* endangered, *VU* vulnerable, *NT* near threatened. Numbers in the table refer to the papers reporting the effects: (1) AOPK (2011); (2) Atay (2012); (3) Bauerfeind et al. (2009); (4) Beneš et al. (2002); (5) Bergman (1999); (6) Bolotov (2011); (7) Brommer and Fred (1999); (8) Casacci et al. (2011); (9) Cassel and Tammaru (2003); (10) Cassel et al. (2008); (11) Cerrato et al. (2014); (12) Cozzi et al. (2008); (13) Čelik et al. (2009); (14) Čelik (2013); (15) de Arce-Crespo et al. (2009); (16) Dennis and Eales (1997); (17) Dincă et al. (2009); (18) Dincă et al. (2010); (19) Dinca et al. (2013); (20) Dolek and Geyer (1997); (21) Eichel and Fartmann (2008); (22) Elmes et al. (1998); (23) Freese et al. (2005); (24) Freese et al. (2006); (25) Goffart et al. (2010); (26) Grill and Cleary (2003); (27) Habel et al. (2011a); (28) Habel et al. (2011b); (29) Höttinger (2004); (30) Hüseyinoğlu (2013); (31) Johannesen et al. (1997); (32) Joy and Pullin (1997); (33) Joy and Pullin (1999); (34) Kadlec et al. (2009); (35) Kajzer-Bonk et al. (2013); (36) Kodandaramaiah et al. (2012); (37) Kolev (2003); (38) Kolev (2005); (39) Konvička and Kuras (1999); (40) Konvička et al. (2005); (41) Konvička et al. (2008a); (42) Konvička et al. (2008b); (43) Konvička et al. (2014); (44) Koren et al. (2011); (45) Koren and Jugovic (2012); (46) Kozlov and Kullberg (2008); (47) Kudrna et al. (2015); (48) Kuras et al. (2003); (49); Louy et al. (2007); (50) Łozowski et al. (2014); (51) Luoto et al. (2001); (52) Meier et al. (2005); (53) Möllenbeck et al. (2009); (54) Munguira and Martín (1993); (55) Obregón et al. (2014); (56) Örvössy et al. (2013); (57) Pennekamp et al. (2013); (58) Pennekamp et al. (2014); (59) Pinzari (2009); (60) Pinzari and Sbordoni (2013); (61) Pocewicz et al. (2009); (62) Rabasa et al. (2007); (63) Rabasa et al. (2008); (64) Sang et al. (2010); (65) Settele (2010); (66) Seufert and Grosser (1996); (67) Schmeller et al. (2011); (68) Schmitt and Rákosy (2007); (69) Shreeve and Smith (1992); (70) Schurian (1995); (71) Simonsen (2005); (72) Spitzer et al. (2009); (73) Streitberger et al. (2012); (74) Szentirmai et al. (2014); (75) Šlancarová et al. (2012); (76) Thomas (1995); (77) Thomas et al. (2001); (78) Välimäki and Itämies (2003); (79) van Halder et al. (2008); (80) van Swaay and Warren (1999); (81) van Swaay (2002); (82) van Swaay et al. (2011); (83) van Swaay et al. (2010); (84) van Swaay et al. (2012); (85) Verovnik et al. (2013); (86) Verovnik et al. (2013); (87) Verovnik et al. (2014); (88) Vrabec (2001); (89) Wiemers et al. (2010); (90) Weking et al. (2013); (91) Wynhoff et al. (2011)

Coenonympha phryne (Pallas, 1771) (van Swaay and Warren 1999).

Mowing should optimally take place outside the flight periods of target butterfly species so as to maintain high availability of nectar sources for their imagoes, and a sufficient number of host plants for oviposition (Johst et al. 2006; Mládek et al. 2006; Dover et al. 2010; Wynhoff et al. 2011). This may be a serious limitation if several target

Fig. 1 Numbers of European butterfly species of conservation concern affected by various types of habitat management. *Shades of gray* indicate different conservation status according to the European Red List of Butterflies (van Swaay et al. 2010): *NT* near threatened, *VU* vulnerable, *EN* endangered, *CR* critically endangered



species occur sympatrically at the same site, which is frequently the case with *Maculinea* butterflies (Sliwinska et al. 2006). In fact, mowing timing must be further restricted in the case of *Maculinea* butterflies due to their myrmecophilous lifestyle (Thomas 1995; Witek et al. 2011). Since the adoption of larvae by ants is a key process for *Maculinea* survival (Thomas 1995; Witek et al. 2010; Sielezniew and Rutkowski 2012), mowing should be conducted only after adoption occurs, i.e., in the second half of September at the earliest (Grill et al. 2008); this guideline likely applies for the conservation of other myrmecophilous butterflies. Furthermore, strong association with ants, which depend on microhabitat conditions in the soil (Elmes et al. 1998), precludes the use of mulching mowers for the management of sites inhabited by myrmecophilous species (Marhoul and Turoňová 2007). In general, mulching is the most devastating method of mowing meadows (Humbert et al. 2010), and it should be discouraged. In addition, Humbert et al. (2010), who investigated the effects of different moving techniques on meadows, found that using motor bar mowers is much better than utilizing rotary mowers.

Extensive grazing

Historically, extensive grazing was applied in grasslands and woodlands together with other types of management. It constituted an effective way of suppressing vegetation succession, thus improving the quality of habitats for numerous butterfly species. In order to benefit butterfly communities, grazing has to be appropriately planned according to its load (i.e., number of livestock units per area unit), types of grazing animals, and grazing period (Morris 2000; Háková et al. 2005; Pöyry et al. 2006). A generally accepted rule is that the optimal sampling intensity should be 0.2 livestock units per hectare, and it should not exceed 0.5 livestock units; this was proved by various studies, such as those on *Colias myrmidone* (Konvička et al. 2008a) *Carcharodus flocciferus* (Zeller, 1847) (Dolek and Geyer 1997), *Euphydryas desfontainii* (Godart, 1819) (Pennekamp et al. 2013), *Parnassius apollo* (Linneaus, 1758) (Schmeller et al. 2011).

The principle that grazing intensity needs to be limited is well exemplified in the endangered *Lycaena helle* (Denis & Schiffermüller, 1775) (Habel et al. 2011b). The species is a typical meadow specialist, inhabiting humid, semi-natural meadows, which were historically maintained by grazing and haymaking (Konvička et al. 2005; Bauerfeind et al. 2009). The introduction of intensive grazing or mowing resulted in local extinctions of the species. Conversely, leaving such sites without any management leads to meadow overgrowth and the disappearance of the species habitats in the long term perspective (Hula et al. 2004; Habel et al. 2010). An appropriate method of management for *Lycaena helle* involves reducing the intensity of grazing and introducing a mosaic mowing, thereby achieving an imitation of traditional farming methods that used to maintain fine-grained mosaic landscapes with different managements (Skórka et al. 2007). This system is also appropriate for other endangered butterflies, such as *Melitaea aurelia* (Nickerl, 1850) (Kleyer et al. 2007). In contrast, Eichel and Fartmann (2008) argued that intensive grazing can also be beneficial for this species as long as it is done once in a few years and some land fragments are left ungrazed.

The type of farm animals kept is important due to the different ways they graze. Sheep grazing has been shown to have a negative impact on the near threatened species *Polyommatus damon* (Dolek and Geyer 2002). In turn for *Pseudophilotes vicrama* (Christoph, 1887) it is optimal to extensively graze goats and sheep within large fenced enclosures, and to gradually move them over a wide area (Beneš et al. 2002; Grill and Cleary 2003). A related species, *Polyommatus dorylas* (Denis & Schiffermüller, 1775), requires extensive grazing combined with the active removal of bushes and tree seedlings; in contrast, intensive grazing by sheep threatens the persistence of the species (Beneš et al. 2002; van Swaay 2002). The timing and duration of grazing are also important factors (Morris 2000). At localities with endangered butterfly species present it should not be applied during the late spring to mid-summer period as it reduces the availability of larval foodplants and nectar sources for adults. Conversely, grazing is most appropriate during the autumn (September–November) and spring (April) (Konvička et al. 2005).

Trampling

Regular trampling can locally prevent the establishment of vegetation and thus it can supress succession. Historically, butterfly site trampling was caused by grazing animals (Morris 2000; WallisDeVries and Reemakers 2001; Kruess and Tscharntke 2002). Nowadays, artificial trampling by horseback riding, biking or hiking offers a simple and typically costless alternative, which helps to maintain butterfly habitats in early successional stages (Konvička et al. 2005). One species that apparently benefits from trampling is the near threatened *Chazara briseis* (Linnaeus, 1758), which inhabits steppe-like grasslands (Johannesen et al. 1997). After the penetration of its sites by sheep ceased, the species suffered a serious decline in the Czech Republic, most likely due to the expansion of shrubs (Kadlec et al. 2009). The trampling of habitat patches, either through grazing or through various adventurous sports, is also necessary for the near threatened species *Hipparchia statilinus* (Hufnagel, 1766) (Beneš et al. 2002; Pinzari 2009). Contrarily, high intensity trampling can also be detrimental for butterfly populations, as was shown in the case of *Erebia sudetica* (Staudinger, 1861) (Kuras et al. 2003).

Occasional burning

Occasional burning may, in some cases, be beneficial for butterfly populations (McIver and Macke 2014). Burning reduces the expansion of shrubs, and it is particularly useful for vast and abandoned areas. As a disturbance event, burning typically exerts long-term positive consequences by suppressing succession, but it has a negative impact on the affected populations in the short term (Wolf 2002). However, Nowicki et al. (2015) found absolutely no short-term negative impacts of large-scale fires on the metapopulations of *Maculinea teleius* and *M. nausithous*. In any case, two basic rules of the thumb should be followed when applying burning as a conservation management tool in order to minimalize possible negative short-term effects. Firstly, small fragments of land should be left unburnt to serve as refuges from which the neighbouring burnt fragments of land can be recolonized (Konvička et al. 2005; Nowicki et al. 2015). Apart from this, burning should occur in seasons when it is likely to be least harmful, i.e., in winter or early spring. Among other examples, burning in winter months has already been successfully applied for the management of sites occupied by *Pseudophilotes vicrama* (Moore, 1865), *Coenonympha tullia* (Müller, 1764), or *Hipparchia fagi* (Scopoli, 1763) (Dennis and Eales 1997; Marttila et al. 1997; Möllenbeck et al. 2009).

Fallowing

Although (as discussed previously) succession at grassland habitats usually has a negative effect on butterfly communities, there are cases in which vegetation succession can be considered advantageous in its early stages (Skórka et al. 2007; Schirmel and Fartmann 2014). This is particularly true for a relatively large group of butterflies that benefit from the occurrence of high vegetation or shrubs within their grassland habitats. For example, overgrown localities with high grasses and abundant shrubs are optimal sites for *Lycaena helle* (Skórka et al. 2007; Habel et al. 2011b), and *Carcharodus lavatherae* (Esper, 1783) (Coutsis and Ghavalás 2001). *Thymelicus acteon* (Rottemburg, 1775) is another species that profits from succession in its early stages (Beneš et al. 2002; Louy et al. 2007). In all such cases, fallowing may constitute a viable management option; however, it can be utilized only for a limited time period since the continuation of succession, beyond a certain stage, inevitably results in habitat quality deterioration (Skórka et al. 2007).

Maintenance of sparse forest stands

A majority of woodland butterflies are, in fact, restricted to open habitats within woodlands, which in recent decades have become rare. The reason for this is the abandonment of traditional methods of forest utilization, such as regular clearcuts, tree stand thinning, and forest grazing. The absence of these activities has led to closing of tree canopies and changes in forest vegetation (Kodandaramaiah et al. 2012). Consequently, a number of woodland butterfly species are now endangered in Europe. One such species is *Euphydryas maturna* (Linnaeus, 1758), which requires insulated glades, sunny spots with young ash trees, and a high availability of nectar plants for its survival (Vrabec 2001; AOPK 2011). Similarly, vulnerable butterflies such as *Lopinga achine* (Scopoli, 1763), *Leptidea morsei*

(Fenton, 1882), and *Parnassius mnemosyne* (Linnaeus, 1758) need open and sunny habitats within forests, including sparse stands, clearings or road margins (Konvička and Kuras 1999; Luoto et al. 2001; Välimäki and Itämies 2003; Höttinger 2004; Konvička et al. 2008b; Streitberger et al. 2012). Finally, open habitats are also vital for woodland species with caterpillars using grasses as host plants, for instance *Hipparchia hermione* (Linnaeus, 1764) (Beneš et al. 2002; Pinzari and Sbordoni 2013) and *Erebia sudetica* (Staudinger, 1861) (Kuras et al. 2001, 2003).

Prescribed forest management is therefore essential for the conservation of most woodland butterflies. Recommended measures should include opening canopies, supressing the growth of tree seedlings within forest glades, supporting forest grazing and promoting coppice management (Slámová et al. 2013). Optimally, tree density should be low enough to allow open spots, which are spaced at least every 300 meters and interconnected with forest roads and clearings (Marhoul and Turoňová 2007). Coppicing, i.e., forest use focused on the production of relatively small diameter wood, for a range of uses including firewood, together with grazing ensured a diverse mosaic of forest microhabitats and created suitable sites for woodland butterflies in the past (Buček 2010). Since both activities are no longer economically viable, financial incentives may be needed to trigger them. Maintaining a network of forest roads with wide margins and strips of herb-rich grassland at forest edges is also recommended (Marhoul and Turoňová 2007).

Unfavourable management

Afforestation

The afforestation of formerly open habitats began at the turn of the 18th and 19th centuries, along with the development of modern forestry (Konvička et al. 2005). Currently, afforestation of grassland habitats poses one of the biggest problems for butterflies in Europe, threatening numerous species of conservation concern (van Swaay and Warren 2006; Cassel et al. 2008; Augenstein et al. 2012; Cerrato et al. 2014). It is thus highly regretful that this process is often supported by land management authorities through financial incentives in the form of afforestation grants (MZE 2001). Apart from the direct loss of grassland habitats (van Swaay and Warren 2006), the negative consequences of afforestation stem from the increased fragmentation of remaining habitat patches. Because grassland butterflies have difficulties dispersing through forested landscapes (Nowicki et al. 2014), the effective isolation of existing populations increases, causing overall declines of metapopulations (van Swaay and Warren 2006; Augenstein et al. 2012). *Parnassius apollo* (Linnaeus, 1758) and *Pseudophilotes vicrama* (Moore, 1865) are typical examples of butterfly species that suffer from afforestation (Grill and Cleary 2003; Schmeller et al. 2011).

Drainage

Deliberate drainage or any other processes that drain soil, such as construction works in the vicinity of wet habitats, is a common problem for endangered butterfly conservation (WallisDeVries and Ens 2010; Kati et al. 2012). Wet meadow specialists, such as *Melitaea britomartis (*Assmann, 1847) (Cerrato et al. 2014) or *Coenonympha tullia*, are particularly threatened by drainage because their host plants depend on adequate soil water levels (Dennis and Eales 1997). The same is true for myrmecophilous species such as *Maculinea* butterflies (Elmes et al. 1998). While drainage in the past was primarily conducted in order to increase the area of arable land, nowadays it is typically imposed as a flood prevention measure, also within protected areas (Mládek et al. 2006). However, there is little justification for such actions, at least from the conservation point of view. A recent study by Kajzer-Bonk et al. (2013) proved that a large-scale flood had absolutely no negative impact on the metapopulations of *Maculinea nausithous* and *M. teleius*, which provides a strong argument against 'conservation-oriented' drainage works.

Intensive agriculture

In many European countries, the current agriculture policy focuses on the intensification of land use and the application of modern agrotechnical methods in order to maximise economic benefits (Mládek et al. 2006; Pöyry 2007). Obviously, any conversion of former grassland habitats to cultivated farmlands will always imply habitat destruction for grassland butterflies (Konvička et al. 2005). Furthermore, the excessive use of insecticides within farmlands has a negative impact on butterfly communities in neighbouring areas (van Swaay and Warren 2006). Nevertheless, even traditional meadow management in the form of mowing and/or grazing may play a negative role if its intensity is too high. Several studies have demonstrated that intensive grazing and mowing lead to a decrease in butterfly species abundance (Balmer and Erhardt 2000; Hula et al. 2004; Saarinen and Jantunen 2005). This negative effect is caused by a significant reduction in the availability of larval host plants. Therefore, meadow specialists with strict trophic requirements, e.g., *Maculinea arion* (Casacci et al. 2011), *M. nausithous, M. teleius* (Witek et al. 2010), and *Coenonympha hero* (Cassel and Tammaru 2003), tend to suffer most. Intensive agriculture has a negative effect on other species as well, with *Coenonympha oedippus* (Fabricius, 1787) (Örvössy et al. 2013), *Muschampia cribrellum* (Eversmann, 1841) (Dincă et al. 2010), and *Plebejus pylaon* (Fischer, 1832) (Munguira and Martín 1993) serving as examples.

Intensive forestry

Just as farming intensification decimates the populations of many grassland butterflies, forestry intensification can also bring about negative consequences for their forest dwelling counterparts. Intensive forestry has caused the abandonment of traditional practices, such as forest grazing and coppicing that benefited butterfly communities in the past (Slámová et al. 2013). There are numerous species of conservation concern among butterflies negatively affected by forestry intensification, including *Coenonympha tullia, Erebia sudetica*, *Euphydryas maturna*, *Hipparchia hermione*, *Leptidea morsei, Lopinga achine* and *Parnassius mnemosyne* (Dennis and Eales 1997; Luoto et al. 2001; Kodandaramaiah et al. 2012; Streitberger et al. 2012; Čelik 2013; Pinzari and Sbordoni 2013; Konvička et al. 2014). To reverse the current negative trends for all these species, changes in forestry management are highly desirable. Forest management must not be focused exclusively on maximising economic benefits from wood production. Specifically, forest stands should be thinned and occasional sunny enclaves should be created.

Discussion

Prior to any human land use, grasslands as well as open places within forests, i.e., the habitats preferred by a majority of European butterflies, used to be sustained by large herbivore grazing, which prevented forest growth (Konvička et al. 2005; Pöyry et al. 2005; Krauss et al. 2005; Stefanescu et al. 2009). The co-existence of various herbivore species with varying feeding preferences and abundances led to strong spatial heterogeneity in herbal vegetation, while fluctuating grazer densities increased temporal dynamics of habitats (Morris 2000; Saarinen and Jantunen 2005; Öckinger et al. 2006; Rösch et al. 2013). Trampling providing continuous disturbance and the provision of dung which fertilised soils were additional positive impacts. All the aforementioned factors resulted in high plant species richness, which in turn benefited butterfly communities as well as various other insect taxa (Van Klink et al. 2015).

With increasing human population in Europe, wild grazers were decimated or even completely exterminated (e.g., aurochs), but since ancient times their role in maintaining butterfly habitats in favourable state was replaced by human activities (Bakker et al. 2004; Van Klink et al. 2015). Traditional agriculture supported the existence of a diverse mosaic of flower meadows mowed with variable intensity and timing, extensively grazed hillsides, and country roads (Balmer and Erhardt 2000; Morris 2000; Konvička et al. 2005). In turn, forest areas, comprising the second most important butterfly habitat (Warren and Bourn 2011), used to be cut frequently, which provided sufficient amount of sunny places (Kodandaramaiah et al. 2012; Fartmann et al. 2013; Slámová et al. 2013). During the twentieth century, mechanisation in both agriculture and forestry brought the era of intensive land use (Young et al. 2005; Wrbka et al. 2008; Korösi et al. 2014), and the traditional land use practices were no longer economically viable (Konvicka et al. 2005; Henle et al. 2008). Consequently, the land became either intensively used or abandoned, which led to population declines in numerous butterfly species (Dover et al. 2010; Horák et al. 2013; Loos et al. 2014).

In order to reverse the negative impacts of changes in agriculture on biodiversity the European Union has reformed its Common Agricultural Policy, focusing it on achieving an optimal balance between food production and sustaining biodiversity (Henle et al. 2008; Wrbka et al. 2008; EEA 2011). Currently, one of its most important instruments are agri-environmental schemes, which subsidise farmers for applying biodiversity-friendly agricultural practices, often resembling the traditional ones (Wätzold et al. 2008; Wrbka et al. 2008). Nevertheless, the pan-European mechanisms of Common Agricultural Policy have so far failed to improve the situation for butterflies, especially those of conservation concern (Henle et al. 2008; Warren and Bourn 2011).

If no further actions are taken, it is most likely that butterfly populations will keep declining and species extinctions will continue. Therefore, it seems necessary that butterfly persistence in semi-natural habitats of Europe is supported with appropriate conservation-oriented management of their sites, e.g., within nature reserves or Natura 2000 areas (van Swaay and Warren 2006; Pöyry 2007; van Swaay et al. 2012). Our review offers some rule-of-thumb recommendations in this respect.

The baseline should be stopping further destruction or devastation of butterfly habitats through ill-conceived management activities, such as afforestation of open lands or drainage works. However, the elimination of unsuitable management alone is not enough to improve the status of endangered butterfly species (van Swaay and Warren 2006; WallisDeVries and Ens 2010; van Swaay et al. 2012). If left abandoned, their habitats will gradually deteriorate in quality, and eventually they will turn into forest through vegetation succession (Bartel and Sexton

2009). Consequently, it is necessary to implement practices aimed at preventing succession processes.

Extensive grazing and rotational mowing have been demonstrated to be the most suitable types of management in this respect, benefiting various groups of endangered butterflies (Dover et al. 2010). These types of management imitate the traditional way of meadow use (Saarinen and Jantunen 2005; Loos et al. 2014). D'Aniello et al. (2011), who compared the effects of grazing and mowing for meadow butterflies, found that grazing is generally more effective in maximising the number of butterfly species occurring in meadows; however, low intensity mosaic mowing provides almost equally positive results.

Trampling is an integral part of grazing, and it typically supports butterfly communities as well (Morris 2000). In areas lacking grazing, trampling can be achieved through various sport activities, e.g., hiking, biking, or horseback riding (Konvička et al. 2005). It has also been found that occasional small area burning is beneficial for a wide spectrum of butterfly species (Möllenbeck et al. 2009; McIver and Macke 2014). In addition, the active removal of shrubs and young trees may at times be necessary, especially because even their minor expansion threatens the populations of some butterfly species (Stefanescu et al. 2009). Conversely, certain species may actually profit from the presence of bushes within their habitats; therefore, the initial stages of succession should be allowed in such cases (Stuhldreher and Fartmann 2014). Other specific management types are suitable for butterflies associated with forests. For a relatively large group of endangered woodland species, maintaining (or, if necessary, establishing) forest glades and other sunny enclaves, as well as thinning forest stands, is recommended (Slámová et al. 2013; Maes et al. 2014).

It is also worth mentioning that apart from targeted management actions as described above butterflies can also benefit indirectly from various other human activities, specifically those suppressing natural succession. A classic example here are military training grounds, characterised by relatively frequent disturbances caused by blasts or heavy vehicles on one hand and the exclusion of intensive agriculture and forestry on the other (Ferster and Vulinec 2010; Rivers et al. 2010). Such conditions result in the formation of heterogeneous landscapes, which often support high diversity of butterflies with various habitat requirements (Warren et al. 2007; Čižek et al. 2013). Abandoned quarries are also known to provide a favourable, if atypical, environment for many animal and plant species (Tropek et al. 2010; Verovnik et al. 2013). Although quarry operations represent a dramatic land degradation; shortly after their abandonment spontaneous succession turns them into diverse habitat mosaics supporting a rich butterfly fauna (Novák and Konvička 2006; Tropek et al. 2010, Čermáková et al. 2010). A similar situation can be observed in other artificial environments especially those created by infrastructure development, such as road margins, railway embankments, gravel pits, or ruderal habitats in suburbia (Van Geert et al. 2010; Lenda et al. 2012; Moron et al. 2014; Nowicki et al. 2013). Nevertheless, it must be underlined that such man-made environments offer favourable conditions only in their early successional stages, hence only in the short-term, and later on they require management just like natural habitats in order to prevent overgrowing.

In our paper, we primarily dealt with management types that should be promoted or prevented at the local scale of butterfly sites. Therefore, it is important to note that the actions favouring butterfly populations at the small-scale, will not necessarily be similarly favourable if applied at the large-scale. The most obvious example is the case of prescribed burning, but the same principle is true also for most other management types discussed. Besides, it should be kept in mind that many suitable management types are interconnected and that there can be no general recommendations on how to manage a particular habitat type. Finding a clear solution concerning the most appropriate management practice for any butterfly species depends on its species-specific habitat requirements, and for this reason it demands profound knowledge of the focal species ecology. Hence deciding an optimal management may be difficult, especially for species with highly specialised requirements (Schirmel and Fartmann 2014). Furthermore, the management of a locality must take into account the requirements of all of the species of conservation concern inhabiting it. These species may in fact have conflicting needs, and prioritising selected species would be essential in such cases (cf. Schmeller et al. 2008).

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