Grasslands of the Palaearctic Biogeographic Realm: Introduction and Synthesis

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Abstract

Grasslands are spontaneously occurring herbaceous vegetation types that are mostly dominated by grasses or other graminoids and have usually >10% herb-layer cover, while woody species area absent or have a significantly lower abundance than the herbs. In the Palaearctic biogeographic realm, natural and secondary grasslands (76% and 24% of all grasslands, respectively) cover about 10.0 million km^2, i.e., 18% of its territory, which constitute 41% of global grasslands—more than any other biogeographic realm. In "The encyclopedia of the world's biomes," the Palaearctic grasslands are placed in the section "Grasslands and shrublands," where we defined 10 regions, which are treated in individual chapters: Western Europe, Northern Europe and Baltic States, Eastern Europe, Mediterranean Region, Middle East and Caucasus, Russia, Kazakhstan and Middle Asia, Mongolia, China, and Japan. These regions cover the huge majority of the realm and about 98% of its grasslands. Each chapter describes the extent, physiogeography, origin, biodiversity and typology of the grasslands in the region, the threats for grassland diversity and extent, as well as grassland management and conservation. Grasslands are important habitats for many groups of taxa. Dry calcareous grasslands and steppes constitute habitat of most of Europe's butterfly and *Orthoptera* species, and they host significant number of European endemic plants. In small spatial scales (i.e., below 100 m^2) Palaearctic grasslands, especially meso-xeric ones, can hold even higher species diversity of plants than tropical rainforests. However, Palaearctic grasslands are also among the most intensively and negatively human-impacted habitats. Changes in grassland management, like overgrazing or other types of intensification as well as abandonment were assessed as the most important recent and future threats. Other important reasons of decline in grassland diversity are habitat loss and altered site conditions. The negative impact of climate change and invasive species is predicted to be stronger in the future. In the last years, various conservation efforts to monitor, maintain and promote grassland extent and diversity were made. However, to counteract the negative trends, these efforts urgently need to be intensified and their efficiency needs to be improved.

Introduction

The Palaearctic biogeographic realm is the largest terrestrial realm on Earth (Olson et al., 2001; see Fig. 1), and grasslands cover a substantial fraction of its territory. The grasslands of the Palaearctic are of diverse type and origin, i.e., natural, semi-natural or anthropogenic. They are a major basis for human food supply and at the same time host a high biodiversity. In this article, we provide an overview on the major grassland types of the realm, including information on origin, spatial extent, and biodiversity.

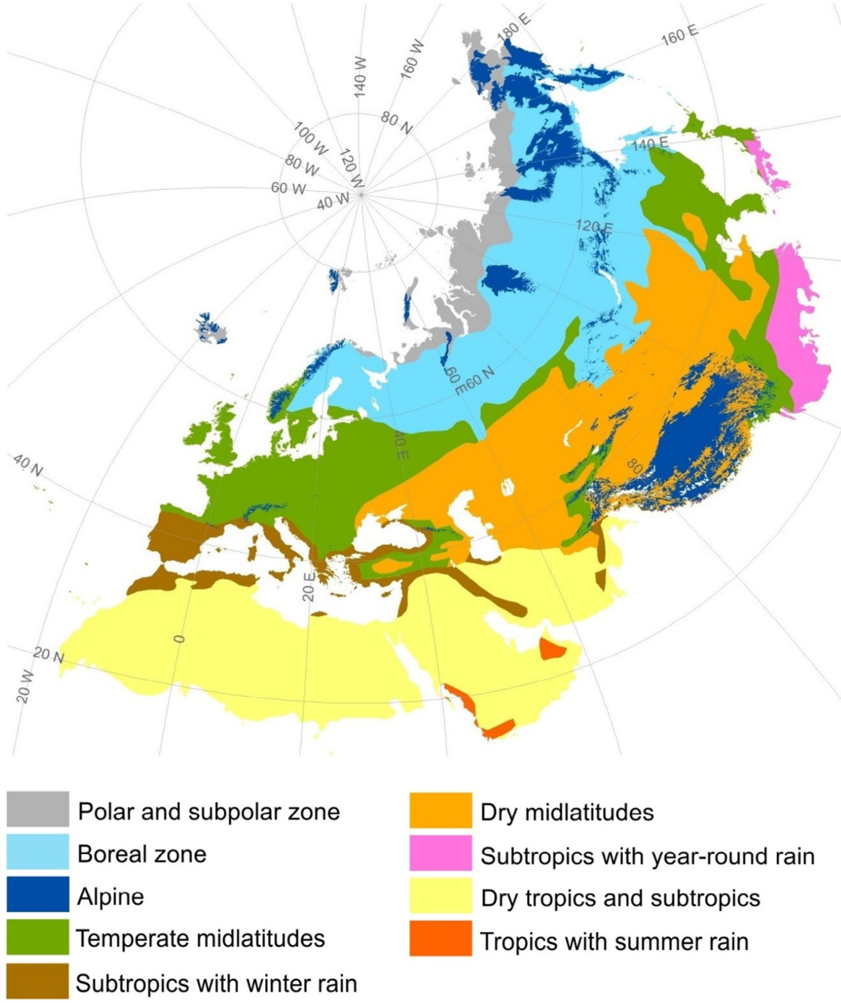

Fig. 1 Delimitation of the Palaearctic biogeographic realm according to Olson et al. (2001) combined with the biome classification of Bruelheide et al. (2019), largely based on Schultz (2005) (map kindly provided by C. Marcenò). Note that according to other concepts, the "Subtropics with year-round rain" do not reach as far north and, for example, most of Japan would belong to the Temperate midlatitudes.

In addition, we outline the causes of regional differences among these factors including the major drivers of biodiversity loss. We largely summarize the knowledge assessed for ten specific chapters on grasslands in different regions of the Palaearctic and some previous syntheses (e.g., Dengler et al., 2014; Wesche et al., 2016; Török and Dengler, 2018). Both the individual chapters and the synthesis have been organized by the Eurasian Dry Grassland Group (EDGG), an international organization dealing with ecology and conservation of all types of natural and semi-natural grasslands of the Palaearctic (Box 1).

In "The encyclopedia of the world's biomes," the Palaearctic grasslands are placed in the section "Grasslands and Shrublands." We defined ten regions, which are treated in individual chapters (Western Europe: Boch et al., 2020; Northern Europe and Baltic States: Dengler et al., 2020b; Eastern Europe: Török et al., 2020; Mediterranean Region: Guarino et al., 2020; Middle East and Caucasus: Ambarlı et al., 2020; Russia: Tishkov et al., 2020; Kazakhstan and Middle Asia: Wagner et al., 2020; Mongolia: Pfeiffer et al., 2020; China: Li et al., 2020; Japan: Ushimaru et al., 2020). The regions cover the huge majority of the Palaearctic biogeographic realm and about 98% of its extant grasslands (Fig. 2 and Table 1). For practical reasons, we delimited the chapters mostly based on political borders, i.e., by combining countries with similar physical geography and/or land-use history. Only the chapter of the Mediterranean Region (Guarino et al., 2020) and partly the one of Western Europe (Boch et al., 2020) apply a more biogeographic delimitation by including some countries only partly (Fig. 2).

The focus of the grassland chapters are natural and semi-natural grasslands and largely exclude arctic-alpine grasslands. However, to provide a comprehensive overview and for consistency reasons, in this synthesis we also cover intensified as well as arctic-alpine grasslands.

Box 1 The Eurasian Dry Grassland Group (EDGG).

The Eurasian Dry Grassland Group (EDGG; http://www.edgg.org), an official working group of the International Association for Vegetation Science (IAVS), was founded in 2008. It has 1314 members, both scientists and conservation practitioners, from 64 countries over the whole Palaearctic (September 2019). With a membership free of any charge, the EDGG coordinates international research on the biodiversity, ecology and conservation of all natural- and semi-natural grasslands of the Palaearctic and initiates respective policy actions. The EDGG is governed by an Executive Committee currently with eight chairs, elected by the membership for 2-years terms. The EDGG facilitates the communication between members by using its mailing list and its open-access electronic journal *Palaearctic Grasslands* with editorial peer review that currently appears in five issues annually. The EDGG organizes yearly conferences (Eurasian Grassland Conferences, EGCs) and Field Workshops (Research Expeditions) for its members. The EDGG is strongly involved in facilitation the establishment of national grassland databases and started the realm-wide database GrassPlot (https://bit.ly/2HvVkgu) with the aim of joining standardized multi-scale datasets collected during the Field Workshops with comparable datasets from other projects to support grassland research and macroecological studies in grassland biodiversity. The EDGG is very active in organizing and publishing thematic issues and special features in and with internationally recognized journals and publishers.

Fig. 2 Subdivision of the Palaearctic biogeographic realm into regions corresponding to chapters in this "Encyclopedia" and/or used in tables and figures of this chapter. The 10 colored regions correspond to one of the EDGG-edited grassland chapters in the "Encyclopedia," while the *white* and *gray* regions are not treated in a specific chapter (map prepared by I. Dembicz).

Table 1 Overview of areas covered by grasslands in the different regions of the Palaearctic biogeographic realm.

Region	*Western Europe*[a]	*Northern Europe and Baltic States*	*Eastern Europe*	*Mediterranean Region*	*Middle East and Caucasus*	Sahara and Arab Peninsula	*Russia*[b]	*Kazakhstan and Middle Asia*	*Mongolia*	*China (Palaearctic part)*	Himalayas south of China	Korean Peninsula	*Japan*	*Total*
Chapter	*Boch et al. (2020)*	*Dengler et al. (2020b)*	*Török et al. (2020)*	*Guarino et al. (2020)*	*Ambarlı et al. (2020)*	–	*Tishkov et al. (2020)*	*Wagner et al. (2020)*	*Pfeiffer et al. (2020)*	*Li et al. (2020)*	–	–	*Ushimaru et al. (2020)*	
Number of countries included	17	9	16	19	9	*20*	1	5	1	1	*5*	*2*	1	99
- Fully included	13	9	16	10	9	*7*	1	5	1	–	*1*	*2*	1	87
- Partly included	4	–	–	9	–	*13*	–	–	–	1	*4*	–	–	12
Total area included [km^2]	1,607,947	1,484,419	1,982,849	1,672,102	3,985,900	*11,258,219*	17,075,400	4,008,139	1,565,000	8,748,897	*779,125*	*220,755*	369,700	54,758,452
Total extant grasslands [km^2]	375,000	103,000	277,500	303,000	1,305,000	*60,000*	1,790,000	1,480,000	1,210,000	2,911,000	*125,000*	*10,500*	24,000	9,974,000
- Fraction of territory	23%	7%	14%	18%	33%	*1%*	10%	37%	77%	33%	*16%*	*5%*	6%	18%
- Proportion of natural grasslands	5%	49%	7%	6%	67%	*100%*	79%	87%	100%	87%	*80%*	*14%*	25%	76%
- Proportion of HNV grasslands	31%	45%	71%	63%	77%	*NA*	91%	76%	77%	74%	*NA*	*NA*	NA	ca. 76%
(1) Natural grasslands (extant) [km^2]	20,000	50,500	18,500	19,000	868,000	*60,000*	1,420,000	1,290,000	1,210,000	2,545,000	*100,000*	*1500*	6000	7,608,500
- As fraction of their original area	75%	89%	8%	NA	NA	*NA*	50%	63%	100%	95%	*NA*	*NA*	NA	ca. 72%
(i) Steppes [km^2]	0	0	11,000	14,000	740,000	*55,000*	500,000	1,120,000	1,090,000	745,000	*65,000*	*0*	0	4,340,000
(ii) Arctic-alpine grasslands [km^2]	10,000	46,500	4500	3000	100,000	*0*	820,000	100,000	100,000	1,198,000	*30,000*	*0*	500	2,412,500
(iii) Azonal + extrazonal grasslands [km^2]	10,000	4000	3000	2000	28,000	*5000*	100,000	70,000	20,000	602,000	*5000*	*1500*	5500	856,000

(a) In good state [km²]	17,500	49,000	12,500	4500	600,000	*NA*	1,278,000	950,000	930,000	1,909,000	*NA*	*NA*	NA	ca. 77%
(b) Strongly degraded [km²]	2500	1500	7000	14,500	268,000	*NA*	142,000	340,000	280,000	636,000	*NA*	*NA*	NA	ca. 23%
(2) Secondary grasslands [km²]	355,000	52,500	259,000	284,000	437,000	*0*	370,000	190,000	0	366,000	*25,000*	*9000*	18,000	2,365,500
- As fraction of their maximum area (in the past)	60%	34%	55%	60%	NA	*NA*	NA	NA	100%	100%	*NA*	*NA*	50%	ca. 64%
(a) Semi-natural grasslands [km²]	100,000	11,500	184,000	187,000	400,000	*NA*	347,000	170,000	0	244,000	*NA*	*NA*	5500	ca. 71%
(b) Strongly intensified grasslands [km²]	255,000	41,000	75,000	97,000	37,000	*NA*	23,000	20,000	0	122,000	*NA*	*NA*	12,500	ca. 29%

The delimitation of the 13 regions is shown in Fig. 2. Ten of the regions are covered in regional chapters, except the three regions set in italics. Note that the areas covered in the articles “Mediterranean Basin” and “Middle East and the Caucasus” slightly overlap; for this synthesis, however, the complete territories of Turkey, Syria and Jordan are treated under the latter despite they also have a share of the Mediterranean Basin. Likewise, the Western Balkan countries Slovenia, Croatia, Bosnia and Hercegovina, Montenegro and North Macedonia in this table are fully counted under “Eastern Europe,” despite they have significant areas in the Mediterranean Region. The numbers provided in this table are mostly rough estimates by the authors of the ten regional chapters and other experts because for the majority of presented facts there are no or no easily accessible hard data. The different grassland categories concerning origin and quality are defined in detail in the text. Fractions of original and maximum areas, respectively, refer roughly to the past 500 years, not to geological time scales. HNV grasslands = High Nature Value grasslands, i.e., natural grasslands in good state and semi-natural secondary grasslands combined. The threshold between the quality categories (a) and (b) is a biodiversity loss of 50%, both for natural and secondary grasslands.

[a]Areas given here deviate from Boch et al. (2020) as these authors based their stats on FAO MODIS (FAO 2019), while we, in agreement with Dengler and Tischew (2018), use FAO CCI_LC (FAO, 2019), which corresponds better to other published stats (Smit et al., 2008; Eurostat, 2015).

[b]Areas for Russia were taken from Reinecke et al. (2018).

Delimitation and Physical Geography of the Region

According to the biogeographic classification by Olson et al. (2001), the Palaearctic biogeographic realm comprises >52 million km^2 on three continents, Europe, Asia, and Africa (Fig. 1 and Table 1). It extends over >20,000 km from west to east (30°W on the Azores to 170°W in the Russian Far East) and over 7000 km from north to south (81°N on Franz-Josef Land in the Arctic Ocean to 17°N on the Arab Peninsula). Thus, the highest (Mt. Everest, 8846 m a.s.l.) and the lowest point (shores of the Dead Sea; 431 m b.s.l.) of the terrestrial surface of the Earth are covered.

The Palaearctic biogeographic realm comprises all terrestrial biomes (Bruelheide et al., 2019) except the "Tropics with year-round rain" (Fig. 1). While the "Subtropics with year-round rain" only occur in East Asia and the "Tropics with summer rain" can only be found in the Southern part of the Arab Peninsula, the other seven biomes are widely distributed: the "Boreal zone," the "Temperate midlatitudes," the "Dry midlatitudes" and the "Dry tropics and subtropics" are the most extensive, the "Polar and subpolar zone," the "Alpine biome" and the "Subtropics with winter rain" (also known as "Mediterranean biome") cover a smaller area. The climate in the Palaearctic biogeographic realm is very diverse. According to the Köppen–Geiger climate classification system the continental climates (group D) prevail in the realm, mostly warm-summer humid continental climate (Dfb) and subarctic climate (Dfc), that are present from Central Europe to the Bering Sea (respectively in the western and in the eastern most parts of the realm). In Western Europe and within several areas of south-eastern borders of the Palaearctic realm, and in South Japan also temperate climates occur (group C). Dry climates (group B) dominate major parts of Central Asia, Mongolia, north-western China, the Middle East, the Arab Peninsula and North Africa (Kottek et al., 2006). The Eastern part of the realm is influenced by the monsoon circulation resulting in large seasonal precipitation variability. In the northernmost regions and in mountain ranges of the realm also polar and alpine climates occur (group E). Mean annual temperature ranges from −29.3 °C to +31.0 °C, and mean annual precipitation from close to 0–3722 mm (Hijmans et al., 2005). Given the huge latitudinal and elevational gradients, it is not surprising that bedrocks and soils are highly variable.

Origin and Extent of the Grasslands

Definition and Types of Grasslands

There are many different definitions of grasslands from ecological, physiognomic, agronomic or remote-sensing points-of-view (Gibson et al., 2009; Dixon et al., 2014; Wesche et al., 2016; Török and Dengler, 2018), which in turn have considerable impact on measuring the spatial extent of grasslands. Here, we follow a slightly modified version of the definition of Török and Dengler (2018), based on earlier suggestions by Janišová et al. (2011) and Dengler et al. (2014):

Grasslands are spontaneously occurring herbaceous vegetation types that are mostly dominated by grasses (*Poaceae*) or other graminoids (*Cyperaceae*, *Juncaceae*) and have a relatively high herb-layer cover (usually >10%), while woody species (dwarf shrubs, shrubs and trees), if present at all, have a significantly lower cover than the herbs.

With "spontaneously occurring," we exclude artificial grasslands that are reseeded every year, such as cereal fields (which otherwise would meet the definition). Deviating from Török and Dengler (2018), we lowered the minimum vegetation cover in the definition from 25% to 10% to match the definition used by FAO (2019). This means that now also desert steppes are fully covered.

Based on their origin, there are two main and five subordinate categories of grasslands (Dengler et al., 2014; Török and Dengler, 2018; see Fig. 3):

(1) *Natural grasslands* (occurring in places where the natural vegetation would also be a grassland, though the current grasslands are potentially modified through human land use)
   (1a) *Steppes* (climatogenic grasslands in climates that are too dry to sustain forests and are affected by frost) (Fig. 3A).
   (1b) *Arctic-alpine grasslands* (climatogenic grasslands in climates that are too cold to sustain forests) (Fig. 3B).
   (1c) *Azonal and extrazonal grasslands* (pedogenic or topogenic grasslands that occur under special soil or topographic conditions that, at small spatial scales, allow grassland to exist in climates that otherwise would support forests, shrublands or deserts; azonal grassland types are those that nowhere form the zonal vegetation, but occur in similar form across two or more biomes, whereas extrazonal grasslands in one biome are similar to zonal grasslands, i.e., steppes or arctic-alpine grasslands, in another biome). Examples of azonal grasslands are salt marshes and coastal dunes (Fig. 3C), while a typical example of extrazonal grasslands are the steppic grasslands that occur on steep south-facing slopes in the forest climate of central Europe (Fig. 3D).
(2) *Secondary grasslands* (occur in places where the natural vegetation is forest, shrubland, heathland or wetland; these grasslands developed under human land use like mowing, grazing, burning or abandoning arable fields)
   (2a) *Semi-natural grasslands* (secondary grasslands in which site conditions except for removing woody species remained more or less unaltered, e.g., no or very little artificial fertilization, no regular reseeding) (Fig. 3E–G).
   (2b) *Strongly intensified grasslands* (secondary grasslands in which the site conditions were altered strongly compared to the natural stage; in particular, with high land-use intensity to increase yield enabled through (artificial) fertilization).

In natural and secondary grasslands high levels of human impact generally reduces biodiversity and conservation value. However, initial, low-level intensification can even increase the biodiversity of certain grasslands, e.g., relatively species-poor extrazonal

Fig. 3 Examples of major grassland categories of the Palaearctic biogeographic realm (A–D: natural grasslands; E–H: semi-natural grasslands): (A) Steppe in Southern Ukraine; (B) Arctic-alpine grasslands form an extensive belt above the timberline in most Palaearctic mountains, here in the Swiss Alps; (C) coastal dune grassland in Sicily, Italy; (D) extrazonal steppic grasslands on steep slopes above the Rhone valley, Switzerland; (E) semi-dry basiphilous grassland in Transylvania, Romania, holding two small-scale world records of vascular plant species richness (see Table 2); (F) eutrophic, wet meadow, Slovenia; (G) extensive semi-natural grasslands, together with arable fields and hedgerows, are part of the traditional cultural landscapes in many parts of Europe, as here in Central Slovakia; (H) in East Asia, semi-natural grasslands are much less extensive, as here on Jeju Island, South Korea (photos by J. Dengler).

steppes in the Swiss inneralpine valleys have been transformed to species-rich meso-xeric grasslands by irrigation (in line with the loss of steppe-specialist species); also a very low level of fertilization or liming of very nutrient-poor and/or acidic secondary grasslands might increase species richness. However, any further land-use intensification (fertilization, higher stocking rates, more cuts per year, drainage, plowing and reseeding, removal of small-scale heterogeneity) will ultimately lead to a strong loss of biodiversity across taxonomic groups (Allan et al., 2014). To capture this process, we differentiate among the *natural grasslands* those "*in good state*" from those that are "*strongly degraded*" and in *secondary grasslands* the "*semi-natural grasslands*" from the "*strongly intensified grasslands*." The natural grasslands in good state and the semi-natural secondary grasslands together are the so-called "*High Nature Value*" *grasslands* (HNV grasslands; Veen et al., 2009; Oppermann et al., 2012; Török and Dengler, 2018). As the loss of "nature value" is a gradual process, we reduced this concept and only distinguish High Nature Value grasslands from grasslands with low nature value. The threshold to distinguish between the two categories was the loss of 50% or more of the original biodiversity. The author teams of the chapters were asked to assess the situation in their particular region based on this definition. While we are not aware of any other definition that connects the concept of "High Nature Value" grasslands (or of the semi-natural grasslands within the secondary grasslands) with clear numbers of biodiversity loss, it is evident that some other publications used much stricter thresholds. When Bullock (2011) reports a loss of 97% of semi-natural grasslands in England and Wales (United Kingdom) since the mid-20th century, this evidently refers to a higher, yet undefined threshold. Definitions of semi-natural grasslands can also refer to other factors than biodiversity, e.g., in Estonia to the fact that a site has never been plowed (S. Rusina, Riga, pers. comm.). Instead of a dichotomy as we apply it here, other systems might use finer delimitations, e.g., Stevens et al. (2010) distinguished "unimproved," "semi-improved," and "improved" grasslands of which the first two approximately correspond to HNV grasslands in our sense. It is important to keep these different delimitations of HNV grasslands in mind when interpreting our Table 1.

Grasslands can also recover after cessation of arable fields, other human disturbance or the removal of afforestations. Actually this is a process that happened repeatedly in many regions of the Palaearctic (Poschlod, 2015; Brinkert et al., 2016; Kämpf et al., 2016) and nowadays is often assisted by restoration measures. For the sake of simplicity, we assign such recovered grasslands depending on their sites to either natural grasslands or secondary grasslands and depending on their quality to either HNV grasslands or non-HNV grasslands (to be kept in mind when interpreting Table 1).

Spatial Extent of Grasslands in the Palaearctic

Quantifying the extent of grasslands in the Palaearctic and its subunits is a major challenge, not only because of the different grassland definitions used in different sources (see above). Even when using the same FAO definition "area dominated by natural herbaceous plants (grasslands, prairies, steppes, and savannahs) with a cover of 10 per cent or more, irrespective of different human and/or animal activities, such as grazing or selective fire management. Woody plants (trees and/or shrubs) can be present, assuming their cover is less than 10 per cent," values for individual countries vary sometimes strongly, depending on whether one refers to the one or the other remote-sensing based product provided by FAO (2019). Sometimes the grassland areas based on MODIS (Moderate-resolution imaging spectroradiometer) are much higher than those based on CCI_LC (Land Cover project of the European Space Agency Climate Change Initiative) (e.g., Turkmenistan: 93,722 MODIS vs. 27,083 km^2 CCI_LC), and sometimes the other way around (e.g., France: 48,791 km^2 MODIS vs. 121,408 CCI_LC); rarely both values are close together (e.g., Italy: 35,357 km^2 MODIS vs. 37,732 km^2 CCI_LC). Similar unexplained inconsistencies, albeit not as strong, were already recorded by Dengler and Tischew (2018) for Western and Northern European countries based on one FAO statistics and two other sources. We tried to use as far as possible national sources to overcome these unexplained inconsistencies, and, when such where not available, averaged the CCI_LC and MODIS-based values of FAO (2019).

According to our compilation (Table 1), there are about 10.0 million km^2 grasslands in the Palaearctic, corresponding to 18% of its territory. In our last, less detailed assessment (Török and Dengler, 2018), we had estimated 9.7 million km^2 and 22%, i.e., the first value is quite similar and the difference in the second can easily be explained by the fact that Török and Dengler (2018) excluded the Arab Peninsula, which hardly contains any grasslands but largely belongs to the Palaearctic biogeographic realm. Comparing these values with the FAO stats for the whole terrestrial surface of Earth (FAO, 2019: mean of MODIS and CCI_LC), it appears that the Palaearctic biogeographic realm comprises approx. 41% of the global grasslands (24.5 million km^2), and thus more than any other biogeographic realm, while the fraction of grasslands here is slightly lower than the global average of 19%. The fractions of grasslands in the 13 regions distinguished range from 1% in the Sahara and Arab Peninsula to 77% in Mongolia (Table 1).

Overall, natural grasslands prevail with 76% vs. 24% secondary grasslands, but in the Europe, the Mediterranean Region, Korea and Japan secondary grasslands dominate, while natural ones often contribute <10% (Table 1). Natural grasslands consist of 57% steppes, 32% arctic-alpine grasslands and 11% azonal and extrazonal grasslands (Table 1). Slightly less than three-fourths of their original extent is still covered by grasslands, but in two regions the loss was particularly dramatic, Eastern Europe with 92% and Russia with 50% (Table 1). The remaining natural grasslands are predominantly (77%) considered as in good state. In those regions, where secondary grasslands nowadays prevail, they were even more widespread in the past, with area losses of typically 40%, but up to 75% in Northern Europe and the Baltic States (Table 1). More than two-thirds of the remaining secondary grasslands belong to our category "semi-natural grasslands," i.e., they still contain at least half of their former biodiversity (Table 1). However, in three of the regions (Western Europe, Northern Europe and the Baltic States, Japan) meanwhile a clear majority of grasslands has been strongly intensified with severe negative impacts on their biodiversity (Table 1).

Biodiversity of Palaearctic Grasslands

Biodiversity Hotspots and Diversity of Taxa in General

Palaearctic grasslands have a significant share of the overall biodiversity of the Earth (for some examples, see Fig. 4). Among the 34 biodiversity hotspots recognized globally (among others defined by the presence of at least 1500 endemic vascular plant species; Mittermeier et al., 2004), six are located in the Palaearctic biogeographic realm: Mediterranean Basin, Caucasus, Irano-Anatolian, Mountains of Central Asia, Himalaya and Japan. All six comprise significant areas of natural and semi-natural grasslands which contribute largely to the overall biodiversity.

Grassland-dominated landscapes are rather young ecosystems in the geological history of the Earth. They originated and expanded in the Cenozoic (from ca. 40 million year), as the effect of the co-evolution of grasses and grazers (Retallack, 2001). In the past, Eurasian steppes supported large herds of wild ungulates such as the saiga antelope, the Przewalski's horse, the Asiatic wild ass, and the Bactrian camel. However, due to human activities most of these species have been extirpated in the wild or survive in only small herds in the Eastern Steppe (Visconti et al., 2018). Grazers typical for alpine grasslands, like ibex, chamois and wild sheep still exist in many mountain ranges in the Palaearctic realm. Other important consumers of plant biomass in grasslands that often play a role of ecosystems engineers in this Palaearctic grasslands are pikas and rodents (Wesche and Treiber, 2012), e.g., ground squirrels, marmots (Fig. 4H), voles, zokors, mole rats, hamsters, gerbils, and jerboas.

Grasslands are also very important for other groups of taxa. It was assessed that in Europe 29% (152 out of 526) of all bird species is associated with grasslands habitats (Nagy, 2014). Dry calcareous grasslands and steppes constitute habitat of 63% of Europe's butterfly species (274 out of 436, van Swaay et al., 2006; Fig. 4E), while in the case of *Orthoptera* (Fig. 4F) even 74% of the species occurring in Europe are dependent on open habitats, mostly grasslands (Hochkirch et al., 2016). European grassland areas also host many species of endemic terrestrial mollusks (Neubert et al., 2019). In the floras of vascular plants of Palaearctic countries, typically the grassland species are the largest group (e.g., Korneck et al., 1998, for Germany); and among the >6000 endemic vascular plant species of Europe those of grasslands (18.1%) constitute the second-largest group after rock-dwelling species (Hobohm and Bruchmann, 2009).

Exceptional Biodiversity at Small Spatial Scales

At small spatial scales (i.e., below 100 m^2) Palaearctic grasslands can hold higher species diversity of plants even than tropical rainforest (Wilson et al., 2012). Meso-xeric grasslands are the most species-rich grasslands (Fig. 3E) in the Palaearctic realm for most spatial scales, both regarding mean and maximum values (Fig. 5 and Table 2). Only at the smallest grain size, 1 cm^2, wet grasslands and mesic grasslands show higher means for vascular plants and total vegetation, i.e., including bryophyte and lichen species, respectively. Maximum richness values of vascular plants correspond specifically to meso-xeric grasslands in Eastern Europe for grain sizes larger than 0.1 m^2 (Table 2), with an outstanding value of 82 species in 1 m^2 (White Carpathians, Czech Republic), 98 in 10 m^2 (Transylvania, Romania; Fig. 3E) and 133 in 100 m^2 (White Carpathians, Czech Republic). Roleček et al. (2019) reported 106 vascular plant species in 10.89 m^2 (3.33×3.33 m) in the mentioned grassland from Transylvania and 119 vascular plant species in 16 m^2 from the Chernivtsi Mts. in Ukraine. For smaller grain sizes, meso-xeric grasslands still show the highest maximum richness for 10 cm^2, but in this case in Western Europe (Navarre, Spain), while a wooded meadow from the Baltic States and a wet grassland from Eastern Europe hold the maximum richness for 100 cm^2 (Estonia) and for 1 cm^2 (Poland), respectively (Table 2). Fig. 6 shows the differences across grain sizes and subregions of mean species richness of vascular plants of the richest vegetation type. Highest means change from Western and Northern Europe in the grain sizes up to 0.1 m^2 to Eastern Europe and Russia in the largest sizes (Fig. 6).

However, bryophytes and lichens exhibit different richness patterns than vascular plants, i.e., being more diverse in other grassland types (Fig. 7). Their fraction changes across the grain sizes, but rocky grasslands and sandy dry grasslands are usually the vegetation types with their highest proportion, with bryophytes normally more abundant in the former and lichens in the latter. Outstanding are the mean bryophyte richness values in wet grasslands (6.4) at 10 m^2 and Mediterranean grasslands (8.1) at 100 m^2, where they constitute 18.3% and 16.1% of the total richness, respectively (Fig. 7). As regards the maximum richness values, rocky grasslands from the Baltic islands (both in Sweden and Estonia) hold the bryophyte records for all grain sizes, as well as the lichen records for most grain sizes, except 1 cm^2 and 100 m^2, for which a sandy dry grassland and a meso-xeric grassland from Germany show the maximum values (Tables 3 and 4). However, Boch et al. (2016a) reported an outstanding value of 36 lichen species on 16 m^2 in a calcareous grassland in Germany (Baden-Württemberg; see dataset Boch et al., 2016b). It is worth to indicate that the fraction of bryophytes and lichens in total vegetation is changing even within particular vegetation types depending on the region. As an example, Fig. 8 (left) shows the fraction of vascular plants, bryophytes and lichens of meso-xeric grasslands across subregions at 10 m^2. Meso-xeric grasslands from northern Europe hold the highest fraction of both bryophytes and lichens, as well as the highest mean richness values of these taxonomic groups. This pattern is conserved in rocky grasslands, which hold the highest fraction of bryophytes and lichens at the level of the Palaearctic realm. Once again, Fig. 8 (right) shows that at 10 m^2 rocky grasslands from Northern Europe hold by far the highest fraction and highest mean values of both bryophytes and lichens, followed by rocky grasslands from Western Europe.

The species richness of other taxa than vascular plants are only rarely reported in the literature. We therefore analyzed data of the Biodiversity Exploratories, a large-scale and long-term functional biodiversity research project (www.biodiversity-exploratories.de/1/home/) where many taxa were sampled on the same plots in 150 differently managed grasslands in three regions of Germany and

Fig. 4 Examples of typical taxa of Palaearctic grasslands: (A) *Stipa capillata*, a representative of one of the most-widespread drought-adapted tussock grass genera of the realm; (B) *Astragalus exscapus*, representing one of the most species-rich genera of Palaearctic forbs and dwarf shrubs; (C) geophytes, like *Colchicum autumnale*, play a lesser role in only some grassland types; (D) *Abietinella abietina* is a widespread moss species of dry grasslands; (E) *Iphiclides podalirius* is a typical butterfly of dry grasslands throughout most of the Palaearctic; (F) *Arcyptera fusca* is a herbivorous *Orthoptera* species grazing in dry grasslands; (G) family of Greylag geese (*Anser anser*) feeding in a wet grassland; (H) Alpine marmot (*Marmota marmota*), a grazer from the genus *Marmota*, which occurs with several medium-sized species in alpine grasslands as well as steppes (photos by J. Dengler).

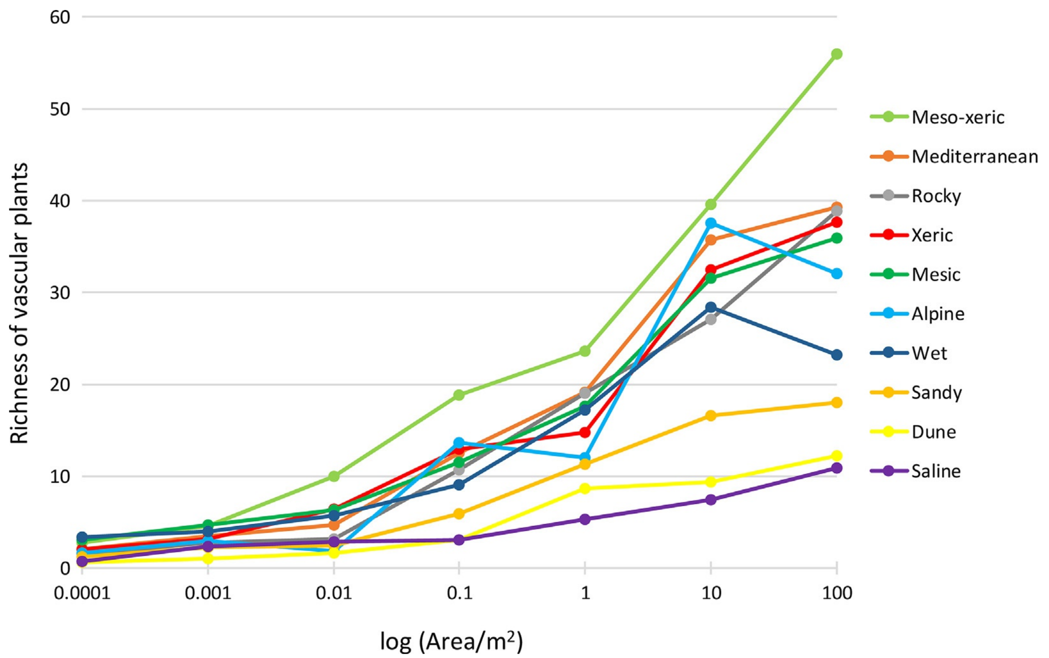

Fig. 5 Vascular plant richness of Palaearctic grasslands across grain sizes and 10 major grassland types. The values are means of all plots in each grain size across the Palaearctic biogeographic realm that were contained in version 2.00 of the GrassPlot database (Dengler et al., 2018; Biurrun et al., 2019).

Table 2 Maximum richness of vascular plants across regions of the Palaearctic realm, as considered in the Encyclopedia.

Area (m^2)	*Western Europe*	*Northern Europe and Baltic States*	*Eastern Europe*	*Mediterranean Region*	*Middle East and Caucasus*	*Russia*	*Kazakhstan and Middle Asia*	*Mongolia*	*China*	*Japan*	*Place and grassland type of Palaearctic maximum*
0.0001	9	5	**11**	8	3	5	5	–	–	–	Poland: wet grassland
0.001	**19**	12	13	12	4	9	15	–	–	–	Spain: meso-xeric grassland
0.01	23	**25**[a]	22	24	20	17	17	–	–	–	Estonia: meso-xeric grassland in a wooded meadow
0.1	34	35[b]	**43**[c]	37[b]	34	28	28	–	–	–	Romania (shoot; Fig. 3E) and Czech Republic (rooted)[c]: meso-xeric grassland
1	53	49	**82**[c]	48	48	52	37	11	59	58	Czech Republic: meso-xeric grassland
10	86	49[b]	**98**	71	65	76[d]	50	–	71[b]	–	Romania: meso-xeric grassland (Fig. 3E)
100	110	70	**133**[c]	99	85	109[d]	67	34	76	–	Czech Republic: meso-xeric grassland

Richness is provided for the grain sizes from 1 cm^2 to 100 m^2. Data from version 2.00 of the GrassPlot database (Dengler et al., 2018; Biurrun et al., 2019), except for values marked by superscript numbers. Palaearctic maximum richness values are indicated in bold.

[a]Chytrý et al. (2015).

[b]Records are for 10% smaller areas, i.e., 0.09 and 9 m^2, respectively.

[c]Wilson et al., 2012.

[d]Unpublished data provided by M. Chytrý.

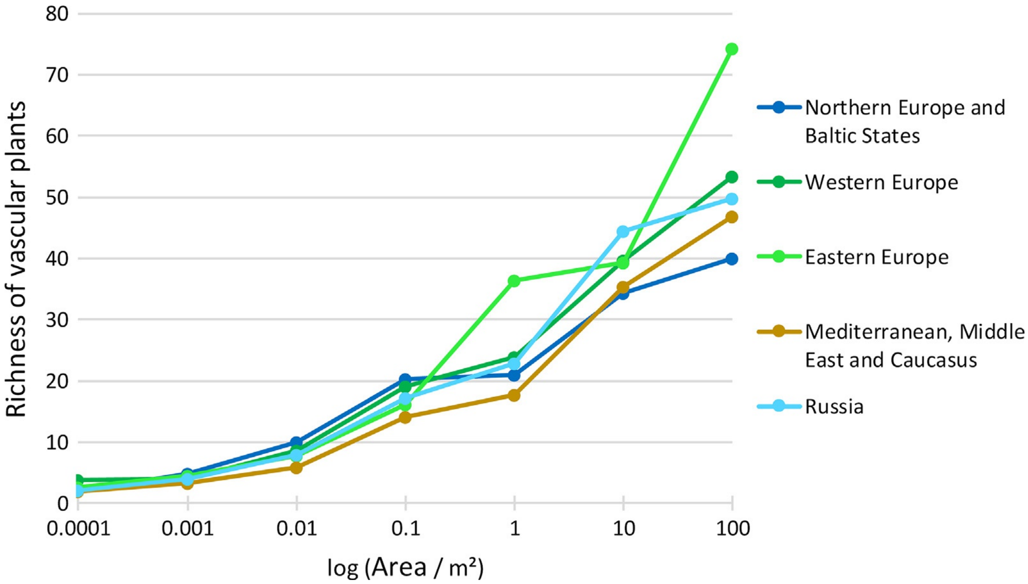

Fig. 6 Mean vascular plant richness of meso-xeric grasslands across grain sizes and Palaearctic regions. Note that the Mediterranean Region and Middle East and Caucasus were joined to get sufficient number of plots in some grain sizes. Japan and Korea, Kazakhstan and Middle Asia, China and Mongolia are not included, because there are not data of meso-xeric grasslands at any grain size, or only at one.

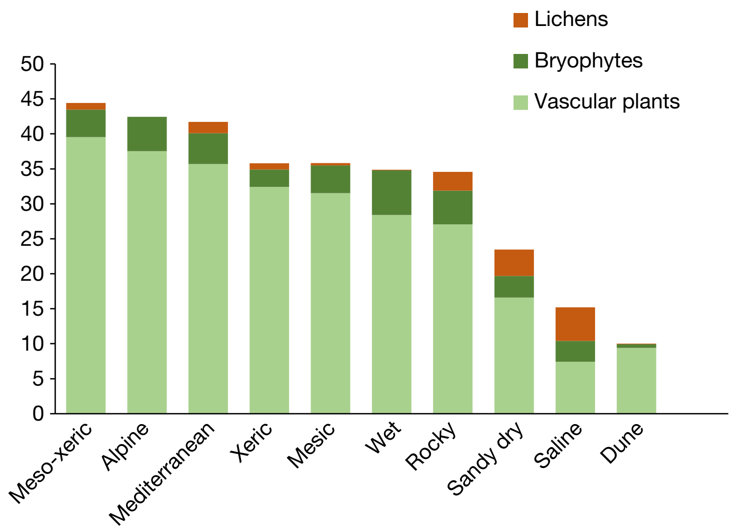

Fig. 7 Species richness and taxonomic composition of the vegetation of 10 major grassland types. The values are means of all the 10-m^2 plots across the Palaearctic biogeographic realm that were contained in version 2.00 of the GrassPlot database (Dengler et al., 2018; Biurrun et al., 2019). Mean richness values of bryophytes and lichens are calculated only for those plots in which they were recorded. Note that the relatively high fraction of non-vascular plants in saline grasslands is due to the fact that non-vascular plants were recorded only in a small subset of these that is not typical for saline grasslands in general.

used for synthesis analyses (e.g., Allan et al., 2014; Blüthgen et al., 2016; Gossner et al., 2016; Soliveres et al., 2016a,b). In plots with a size of 50 × 50 m, on average 3.5 bird species (max. 19; for methodological details see Wells et al., 2011) and 3 bat species (max. 10; years 2008–2012; for methodological details see Heim et al., 2015; Treitler et al., 2016) occurred. Sweep netting along transects in these plots (Simons et al., 2014, 2015, 2016; Neff et al., 2019), revealed on average 19.8 *Hemiptera* (max. 34) and 1.6 *Orthoptera* species (max. 5). As sweep netting largely excludes most ground-dwelling species, e.g., *Araneae* species (spiders) and *Coleoptera* species such as most carabid beetles, the sweep netting approach was combined with pitfall trapping in a subset of 27 plots (Lange et al., 2011; Allan et al., 2014). This resulted in 7.5 and 8.5 times higher mean numbers of *Coleoptera* species (mean 13 vs. 98.1, max. 34 vs. 153 species) and *Araneae* species (mean 3.6 vs. 30.6, max. 11 vs. 56 species), respectively, than the pure sweep-netting approach.

Table 3 Maximum richness of bryophytes across regions of the Palaearctic realm, as considered in the Encyclopedia.

Area (m^2)	*Western Europe*	*Northern Europe and Baltic States*	*Eastern Europe*	*Mediterranean Region*	*Middle East and Caucasus*	*Russia*	*Kazakhstan and Middle Asia*	*China*	*Place and grassland type of Palaearctic maximum*
0.0001	4	**5**	4	**5**	1	3	1	–	Estonia: rocky grassland and Italy: Mediterranean grassland
0.001	6	**9**[a]	7	8	1	4	2	–	Estonia: rocky grassland
0.01	7	**18**	10	9	1	5	2	–	Sweden: rocky grassland
0.1	10	**24**[a]	10	10	2	9	2	–	Sweden: rocky grassland
1	13	**31**	11	18	2	11	3	–	Sweden: rocky grassland
10	27	**40**[a]	18	19	2	13[a]	7	–	Sweden: rocky grassland
100	23	**38**	17	23	3	19	9	2	Estonia: rocky grassland

Richness is provided for the grain sizes from 1 cm^2 to 100 m^2. Data from version 2.00 of the GrassPlot database (Dengler et al., 2018; Biurrun et al., 2019). Palaearctic maximum richness values are indicated in bold. For Mongolia and Japan, GrassPlot 2.00 does not contain plots with records of bryophytes.
[a]Records are for 10% smaller areas, i.e., 0.0009, 0.09 and 9 m^2, respectively.

Table 4 Maximum richness of lichens across regions of the Palaearctic realm, as considered in the Encyclopedia.

Area (m^2)	*Western Europe*	*Northern Europe and Baltic States*	*Eastern Europe*	*Mediterranean Region*	*Russia*	*China*	*Place and grassland type of Palaearctic maximum*
0.0001	**4**	2	2	1	3	–	Germany: sandy grassland
0.001	4[a]	**6**[a]	2	1	2	–	Sweden: rocky grassland
0.01	7	**8**	3	3	6	–	Sweden: rocky grassland
0.1	10[a]	**15**[a]	4	5	8	–	Sweden: rocky grassland
1	11	**21**	8	5	17	–	Sweden: rocky grassland
10	16[a]	**24**[a]	12	10[a]	20	–	Sweden: rocky grassland
100	**31**	25	15	15	28	3	Germany: meso-xeric grassland

Richness is provided for the grain sizes from 1 cm^2 to 100 m^2. Data from version 2.00 of the GrassPlot database (Dengler et al., 2018; Biurrun et al., 2019). Palaearctic maximum richness values are indicated in bold. For Middle East and Caucasus, Kazakhstan and Middle Asia, Mongolia and Japan, GrassPlot 2.00 does not contain plots with records of lichens.
[a]Records are for 10% smaller areas, i.e., 0.0009, 0.09 and 9 m^2, respectively.

Factors Influencing Alpha Diversity of Grasslands

As in all other biogeographic realms and biomes, biodiversity of Palaearctic grasslands is shaped simultaneously by many environmental factors. Therefore it is impossible to point out only one or two major predictors of species diversity. Moreover, the main drivers of biodiversity can be properly indicated only for a given spatial scale (Huston, 1999) and for different taxonomic groups the observed patterns can be opposite (Mateo et al., 2016).

Coarse-scale diversity patterns of plants in Palaearctic grasslands are determined mostly by climate and geological history (Antonelli et al., 2018). With regard to climatic factors, evapotranspiration as a climatic parameter that combines some of the effects of precipitation, temperature, solar radiation, and other factors in a single value seems to be the most important (Huston, 1999), but this still needs to be confirmed for Palaearctic grasslands. The geological history, like formation of mountain ranges, past climate changes and glaciations greatly impacted the current distribution of species. Exceptionally diverse regions, rich in endemic plant species, usually occur in mountainous regions, former glacial refugia, and especially in places with calcareous bedrock (Smyčka et al., 2017; Noroozi et al., 2018; Večeřa et al., 2019).

In a more local scale, plant diversity in grasslands is determined e.g., by primary productivity, fertility and pH of soil, as well as management or natural disturbance regime. In general, primary productivity influences plant species richness according to a unimodal relationship (Fraser et al., 2015). Productivity in grasslands is mostly determined by climate (precipitation, temperature and length of growing season) in case of natural, climatogenic grasslands, while in semi-natural grasslands it also strongly depends on soil fertility. Palpurina et al. (2019) found that the type of nutrient limitation can affect the plant species richness-productivity relationship in Palaearctic dry grasslands: species richness increased more steeply and peaked higher under elevated productivity levels at nitrogen and phosphorus co-limited sites. Similarly to productivity, a hump-shaped relationship was found for soil pH and plant diversity at the regional scale, with highest richness in neutral or slightly basic pH, but in drier conditions this relationship became negative or was not significant (Palpurina et al., 2017).

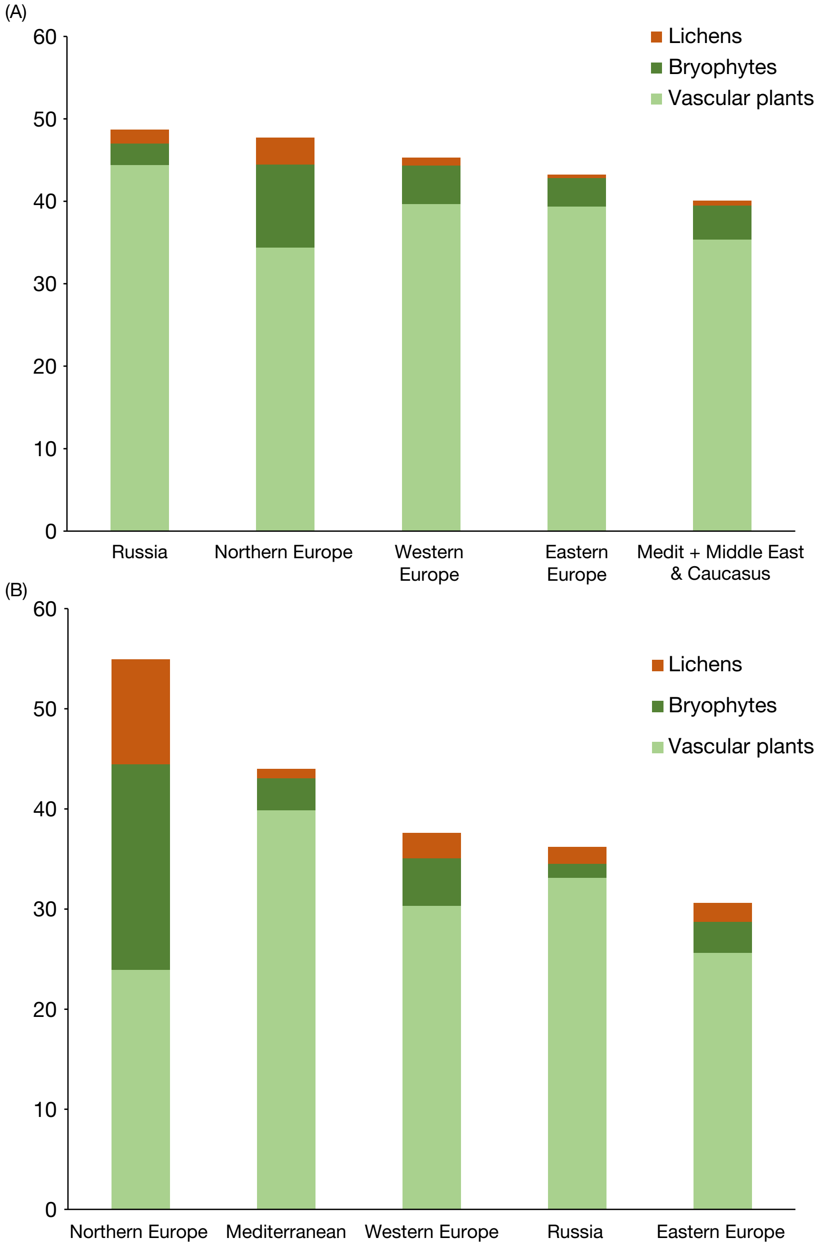

Fig. 8 Species richness and taxonomic composition of the meso-xeric grasslands (*left*) and rocky grasslands (*right*) across Palaearctic subregions. Displayed are means of all 10-m^2 plots contained in version 2.00 of the GrassPlot database (Dengler et al., 2018; Biurrun et al., 2019) in which all three taxonomic groups were recorded. Note that Mediterranean and Middle East & Caucasus were joined for meso-xeric grasslands to get a sufficient number of plots. Japan and Korea, Kazahkstan and Middle Asia, China and Mongolia are not included because of lack of data.

Management is a particularly important driver of species richness in semi-natural grasslands, as abandonment usually is followed by secondary succession towards shrubland or forest communities. Traditional, extensive management, like grazing or mowing, usually supports high diversity of grasslands, while intensification through excessive application of fertilizers, frequent mowing, sowing of highly productive species of grasses and/or legumes, and also too intensive grazing often lead to biodiversity decline (e.g., Socher et al., 2012; Török et al., 2016; Boch et al., 2018). It should be noted that in case of natural grasslands, the natural factors shaping their diversity quite often are disrupted by human activities, thus their biodiversity can also decline if there is no active conservation measure, e.g., replacing grazing by wild animals (that are locally extinct) or natural fires (Havrylenko, 2011).

Species-Area Relationships and Beta Diversity

Extensive multi-scale sampling conducted on Palaearctic grasslands in recent years with application of standardized methodology (Dengler et al., 2016) and other data stored in the GrassPlot database (Dengler et al., 2018; Biurrun et al., 2019) revealed other interesting macroecological patterns. Analyses of data coming from 2057 nested plot series in Palaearctic grasslands (with at least seven grain sizes varying from 1 cm^2 to 1024 m^2) confirmed that the power function $S = c\ A^z$ (where S is the species number, A represents area and c and z are fitted parameters of the function) describes species-area relationships (SARs) in Palaearctic grasslands best (Dengler et al., 2020a).

Moreover, the exponent z of the power function, which describes how fast species richness increases with increasing area, can give valuable ecological information, i.e., on the fine-scale beta diversity. Such beta diversity (called multiplicative beta diversity; Jurasinski et al., 2009) is calculated according to the formula $z = \log_{10}(S_\gamma/S_\alpha)/\log_{10}(A_\gamma/A_\alpha)$, where S_i is the species richness and A_i the area at the α- and γ-level, respectively. Fine-scale beta-diversity is useful in comparing the rate of spatial species turnover between different ecological situations. Analyses performed on 4546 nested plot series in Palaearctic grasslands showed that taxonomic groups significantly differ in this respect with bryophytes having the lowest, and lichens the highest beta diversity (Dengler et al., unpublished). Fine-scale beta diversity of Palaearctic grasslands can be controlled by environmental factors, that can have positive impact like habitat heterogeneity (Polyakova et al., 2016; Dengler et al., unpublished), negative impacts like heat load (proxy of the drought stress) and productivity (Chiarucci et al., 2006; Turtureanu et al., 2014), or unimodal effect as in annual precipitation (Polyakova et al., 2016; Dengler et al., unpublished).

Threats and Conservation

Overall Threat Assessment

In the Palaearctic region, grasslands are important habitats for many species of global conservation concern (Habel et al., 2013; Török et al., 2016; Török and Dengler, 2018). These type of terrestrial habitats are among the most intensively and negatively human-impacted ones, characterized by a strong declining trend in habitat extent (see Table 1) and intactness as well as species diversity and abundance since the second half of the 20th century (Visconti et al., 2018). Because of that, a high proportion of grassland types (e.g., Janssen et al., 2016) and associated species are endangered today (Visconti et al., 2018). Alarming losses of species abundances in a rather short time period and the homogenization of species communities by supporting generalist species at the expense of habitat specialists were reported for well-monitored taxa such as farmland birds (57% population decrease) and grassland butterflies (45% population decrease) in Western and Central Europe (Visconti et al., 2018). Mollusk abundance and diversity has also declined with grassland intensification or conversion to arable land (Neubert et al., 2019).

In Table 5, we summarize the major threats to grassland biodiversity in the 10 regions of the Palaearctic biogeographic realm, separated in drivers of biodiversity loss during the past decade and projected change of the impact of these drivers in the next decade. The table was mainly based on expert assessments by the author teams of the ten regional chapters, combined with the findings of the IPBES regional assessment report on biodiversity and ecosystem services for Asia and the Pacific (Karki et al., 2018) as well as for Europe and Central Asia (Rounsevell et al., 2018). We used a comprehensive classification of drivers with 16 threat categories, arranged in six main groups, updated from Török and Dengler (2018).

Generally, the drivers of the category "changes in grassland management" were considered as the most negative ones (Table 5). While in Mongolia and China, overgrazing is the major cause of biodiversity loss, in the more oceanic areas (with prevailing secondary grasslands), the "twin threats" of abandonment/underuse and other forms of intensification than overgrazing have this role (Table 5). Habitat loss generally is the second most important driver of biodiversity loss of grasslands, with built-up areas, arable fields and afforestation being seen as similarly important, but with regional differences (Table 5). Up to now, on average 28% of the natural grasslands and 38% of the secondary grasslands got completely lost that way, but regionally losses are much more dramatic, with up to 92% for natural grasslands (Eastern Europe) and 75% for secondary grasslands (Northern Europe and Baltic States). Altered site conditions in general were of only moderate impact on biodiversity currently, with the exception of eutrophication, which is one of the most important drivers in Western Europe, and to a lesser extent in Northern Europe and the Baltic States. In Europe formerly also drainage of wet grasslands was a major course of biodiversity loss (Wesche et al., 2009), but the large-scale drainages are largely history, while nowadays locally even re-wetting projects are performed. The three other driver groups, climate change, invasive species and direct impact of humans and their infrastructure were generally considered of lesser importance, but also with some regional differences (Table 5). When projecting the current trends into the future, the regional author teams largely assumed that the same drivers that cause biodiversity loss today will continue to do so at a similar level in the next 10 years (Table 5). The only two drivers where a significant proportion of regional author teams predicts stronger negative impact in the future are climate change and invasive species.

Individual Threat Factors

Land-use change (including changes from intensification to the complete abandonment) was identified as the major driver of habitat degradation, large-scale biodiversity loss and homogenization of species assemblages by the IPBES assessment (Visconti et al., 2018), consistent with our own assessment (Table 5). On the one hand, intensification of land use aims to increase the productivity of grasslands; it is mostly achieved with the addition of organic or inorganic fertilizers and the broadcast of high-production grass and forb cultivars. Productive grasslands are mown more frequently or grazed at higher stocking densities compared to extensively managed grasslands (Blüthgen et al., 2012). Intensive management promotes a few mowing-tolerant species (e.g., Socher et al., 2012) or leads to diversity loss due to overgrazing (Török et al., 2016). The conversion of a large

Table 5 Overview of the main drivers of grassland biodiversity loss, their current impact (i.e., rate of biodiversity loss caused by them 2010–2019) and its anticipated future change (i.e., change in the rate of biodiversity loss in 2020–2029 compared to the situation in 2010–2019).

	Western Europe		Northern Europe and Baltic States		Eastern Europe		Mediterranean Region		Middle East and the Caucasus	
Driver	**Current impact**	**Future change**	**Current impact**	**Future change**	**Current impact**	**Future change**	**Current impact**	**Future change**	**Current impact**	**Future change**
Habitat loss										
Conversion to arable land	High	± Constant	Low	± Constant	Medium	± Constant	Low	± Constant	Low	± Constant
Afforestation	Medium	± Constant	Medium	± Constant	Medium	± Constant	Low	± Constant	High	± Constant
Mining and energy production[a]	Low	Decrease	Low	± Constant	Low	± Constant	Low	± Constant	Medium	Increase
Settlements and other infrastructure	Medium	± Constant	Low	± Constant	Low	± Constant	Medium	± Constant	Medium	± Constant
Changes in grassland management										
Abandonment and underuse	High	± Constant	High	Increase	Very high	± Constant	Medium	Increase	High	± Constant
Overgrazing	Medium	± Constant	Medium	± Constant	Low	± Constant	Medium	± Constant	Low[b]	± Constant
Other forms of intensification[c]	Very high	± Constant	High	± Constant	Medium	Increase	Low	± Constant	Low	± Constant
Altered site conditions										
Eutrophication (direct and indirect)[d]	Very high	± Constant	Medium	± Constant	Low	± Constant	Low	± Constant	None	± Constant
Altered water regime[e]	Medium	± Constant	Low	± Constant	Low	± Constant	Low	± Constant	Low	NA
Climate change	Low	± Constant	Low	Increase	Low	Increase	Medium	Increase	Low[f]	Increase
Invasive species	Medium	± Constant	Low	± Constant	Medium	Increase	Medium	± Constant	Low	Increase
Direct impact of humans and their infrastructure										
Military and armed conflicts	None[g]	± Constant	None[g]	± Constant	Low	± Constant	Low	± Constant	Medium	± Constant
Recreation activities	Low	± Constant	Low	± Constant	Low	Increase	Low	± Constant	Low	± Constant
Collecting wild plants and hunting	Low	± Constant	Low	± Constant	Low	± Constant	Low	± Constant	Medium	± Constant
Wildlife loss due to electrocution, wind farm collision or traffic	Low	± Constant	Low	± Constant	Low	± Constant	Low	± Constant	None	NA
Wildfires caused by humans	None	NA	None	NA	None	NA	Medium	± Constant	None	NA

Table 5 (Continued)

	Russia		Kazakhstan and Middle Asia		Mongolia		China		Japan	
Driver	**Current impact**	**Future change**	**Current impact**	**Future change**	**Current impact**	**Future change**	**Current impact**	**Future change**	**Current impact**	**Future change**
Habitat loss										
Conversion to arable land	Medium	± Constant	Medium	± Constant	Low	± Constant	Low	± Constant	None	± Constant
Afforestation	Low	± Constant	Low	± Constant	None	± Constant	Low	± Constant	Low	± Constant
Mining and energy production[a]	Low	± Constant	Low	± Constant	Medium	Increase	Medium	± Constant	None	± Constant
Settlements and other infrastructure	Low	± Constant	Low[f]	± Constant	Medium	Increase	Medium	± Constant	Medium	Increase
Changes in grassland management										
Abandonment and underuse	High	± Constant	Medium[h]	± Constant	Low	± Constant	Low	± Constant	High	Increase
Overgrazing	Medium	± Constant	Medium	Increase	High	Increase	High	± Constant	Low	± Constant[i]
Other forms of intensification[c]	Medium	± Constant	Low	± Constant	Low	± Constant	Low[j]	± Constant[j]	High[k]	Increase[k]
Altered site conditions										
Eutrophication (direct and indirect)[d]	Low	± Constant	Low	± Constant	None	± Constant	Low	± Constant	Low[l]	± Constant
Altered water regime[e]	Medium	± Constant	Medium	± Constant[m]	None	Increase	Low	± Constant	None	± Constant
Climate change	Low	± Constant	Low	± Constant	Medium	Increase	Medium	Increase	Low	Increase
Invasive species	Medium	Increase	Low	Increase[l]	None	± Constant	Low	± Constant	Low[n]	± Constant
Direct impact of humans and their infrastructure										
Military and armed conflicts	Low	± Constant	Low	± Constant	None	± Constant	None	± Constant	None[o]	± Constant
Recreation activities	Low	Increase	Low	± Constant	Low	Increase	Low	± Constant	Low[p]	± Constant
Collecting wild plants and hunting	Medium	± Constant	Medium	± Constant	Medium	± Constant	Medium	± Constant	Low	± Constant[q]
Wildlife loss due to electrocution, wind farm collision or traffic	Medium	± Constant	Medium[r]	± Constant[r]	Low[s]	± Constant[s]	NA	NA	Low[t]	Increase
Wildfires caused by humans	High	Increase	Medium[u]	Increase[u]	Low	± Constant	Low	± Constant	None	± Constant

"Current impact" is given on a five-step ordinal scale (none—low—medium—high—very high), while "Future change" was assessed on a three-step ordinal scale ("decrease"—"±constant"—"increase"), where "±constant" means that the biodiversity loss due to this driver is expected to continue in the next decade at the same level as in the previous decade (±10%). Please note that in order to get an assessment of the expected impact during the next decade, both columns have to be combined: for example, if the current impact is "medium" and the future change is predicted to be an "increase," the future impact would be "high" (or even "very high"). Likewise, even if the importance of a driver is predicted to decrease, it will in most cases still cause additional biodiversity loss during the next decade. "NA" = not assessed.

[a]This includes area loss due to open-cast mines and water dams for energy production.

[b]Overgrazing is not widespread but in some places it is an important driver of biodiversity loss.

[c]This includes high cutting frequency, pesticide application, re-seeding and homogenization of grasslands/removal of heterogeneity.

[d]This refers to direct fertilization, spill-over from neighboring fields and airborne nitrogen input.

[e]This refers both to drainage and irrigation.

[f]Except for the sprawling city of Almaty and its satellite towns ("high").

[g]In the absence of war, military training areas had in the past even a positive or very positive effect on grassland biodiversity, but during the past decade the diversity in these areas remained ±constant.

[h]Abandonment and underuse "high" in steppes of Kazakhstan but "low" in remaining regions.

[i]Overgrazing by livestock is not widespread but biodiversity loss by wild deer browsing will increase in semi-natural grasslands.

[j]Hay making ("low"/"±constant"), use of pesticides ("none"/"±constant").

[k]Paddy consolidation and increased sown pastures.

[l]Generally "none" to "low," but "high" in some meadows.

[m]±Constant because of recent dam reservoir constructions in Pamir-Altay and surroundings.

[n]Generally "none" to "low," but "high" in oceanic islands.

[o]Training grounds for the Japan Self-Defense Forces have maintained semi-natural grassland biodiversity.

[p]Ski slope grasslands have maintained semi-natural grassland biodiversity whereas off-road vehicle recreation degrades coastal and riparian grasslands.

[q]Hunting pressure on wildlife will decrease due to aging of hunters.

[r]Electrocution ("high"/"±constant") and wind farm collisions ("low"/"increase," but "low"/"±constant" in Kirgyzstan and Tajikistan).

[s]Electrocution ("moderate"/"±constant"), wind farm collisions ("none"/"±constant").

[t]Wind farm construction has negative effects on coastal grassland biodiversity in the northern part of the country.

[u]Wild fires variable by region: "very high"/"increase" in steppes of Kazakhstan to "low"/"±constant" in remaining regions.

proportion of semi-natural to intensified grasslands caused a large-scale landscape simplification and homogenization, especially in Western and Central Europe (Visconti et al., 2018). This is resulting in a multi-trophic homogenization of grassland communities, the loss of specialist species and ecosystem multifunctionality (Gossner et al., 2016; Soliveres et al., 2016a,b). On the other hand, the cessation of grassland management in general leads to litter accumulation, increased competition by community generalists and woody encroachment on the long-run. In the future, woodland increase and further grassland declines are particularly projected for Western and Central Europe (Harrison et al., 2018). The cessation of traditional land use is associated also with the loss of indigenous and local knowledge and practices (Elbakidze et al., 2018). However, effects of abandonment might differ among vegetation types, regions and taxa (Kämpf et al., 2016; Valkó et al., 2018). There is evidence for particularly strong negative effect of the cessation of grassland management on the biodiversity in semi-natural grassland systems of temperate regions (Dengler et al., 2014; Rotherham, 2015) and mountain areas (MacDonald et al., 2000; Valkó et al., 2012; Boch et al., 2019). This is in accordance with our evaluation, as the threat group "Changes in grassland management" was identified as the most negative one (Table 5). In addition, abandonment and underuse was identified as an important driver of biodiversity loss in Europe (Western Europe, Northern Europe and Baltic States, and Eastern Europe), but also in the Middle East and Caucasus, Russia or Japan. Also the negative impacts of abandonment were assessed to remain constant or even increase in some regions (Table 5). Another important driver was intensification of land use in form of overgrazing (Mongolia and China) and other forms of intensification mostly for hay making (Western Europe, Northern Europe and the Baltic States and Japan; Table 5).

Habitat loss in the form of conversion to arable land, afforestation, mining and energy production or urbanization (settlements and other infrastructure) was assessed to have a high impact in Western Europe (conversion to arable land) and in the Middle East and the Caucasus (afforestation). In most regions, however, its current impact was assessed from low to medium with a remaining trend for the future. Abandonment of crop production in marginal or low-production cropland areas promotes the recovery of landscape-scale biodiversity, as on the abandoned areas in case of proper sources of propagules available in the landscape grasslands spontaneously regenerates. This type of large-scale recovery was typical for Central Asian steppes after the dissolution of the USSR (Brinkert et al., 2016; Kämpf et al., 2016). This recovery was further associated with increased ecosystem functioning because of increased soil carbon sequestration (Kurganova et al., 2015). In contrast, in Western Europe the reuse of fallow lands is typical – which also resulted in the conversion of spontaneously recovered grasslands. The eutrophication was identified as an important threat for grassland biodiversity in Western Europe (by fertilizer application, aerial nitrogen deposition and run-on of fertilizers from neighboring fields), but having only low impact in most of the other regions. Altered water regime was assessed having currently no to medium impact (but had strong negative impact in some regions in the past).

Negative effects of invasive alien species encroachment include suppression of native species, gene drift, homogenization of species assemblages and modifications of habitats and ecosystem functions. Moreover, invasive alien species might have negative economic and human health consequences (Nentwig et al., 2016, 2018; Elbakidze et al., 2018). Western European countries have the highest numbers of invasive alien species in the Palaearctic realm due to trade and colonial histories, the invasion rates continuously increasing in all environments, taxonomic groups (except mammals), and subregions and there is no sign of reversing or slowing down this trend. However, there are data limitations in large parts of the region outside Europe (Karki et al., 2018; Rounsevell et al., 2018). Although the invasion threat during the 21st century is expected to be medium to very high in most parts of Europe and Central Asia (expect Northern regions), the negative impact of invasive alien species on Palaearctic grasslands so far has been evaluated as low to moderate (Török and Dengler, 2018). In the current assessment a medium impact of invasive species were assessed in Europe (excluding Northern Europe and Baltic States where it was low) and Russia, but was low and even negligible (Mongolia) in other regions. This might be because of the low number of high-impact invasive aliens that are actually associated with grasslands (see Nentwig et al., 2018). However, effects of invasions are expected to increase in future (Table 5) and might be particularly accelerated by climate change, but the outcome will largely depend on effective management and policy measures (Elbakidze et al., 2018).

Climate change is expected to come along with increased temperatures, reduced precipitation and increased numbers of extreme weather events in large parts of the Palaearctic realm. Projected habitat changes can lead to transitions in species composition and diversity loss. While desertification risk is particularly high in Asian steppe regions (Faridah-Hanum et al., 2018; Visconti et al., 2018), mountain and northern grasslands are affected by northwards and upwards shifting thermophilous species, which can cause a decline of cold-adapted, high-elevation species (Gottfried et al., 2012; Steinbauer et al., 2018). Moreover, climate change might accelerate the negative effects of other major drivers of biodiversity loss (Faridah-Hanum et al., 2018; Visconti et al., 2018). In the present assessment, we found the current impact of climate change from low to medium but in most regions an increasing impact was assumed for the future. With climate change spontaneous wildfires and arsons will likely increase, which can have high impact on the biodiversity (we assessed its current impact to be high in Russia).

Further direct human impacts such as military and armed conflicts vary among the regions: In absence of war, for example in Western Europe, Northern Europe and the Baltic States or Japan, military training areas are associated with extensive land use and low accessibility, which is highly promoting grassland diversity. In contrast, grassland biodiversity is threatened by armed conflicts in regions such as Eastern part of Ukraine, the Middle East and Central Asia (Török and Dengler, 2018, Table 5). In most parts of Asia and the Middle East and Caucasus the collecting of wild plants and hunting was assessed to have medium impact on grassland biodiversity. Impact of recreation activities, wildlife loss due to electrocution and wildfires (for the latter two in exception of Russia where they were assessed as medium and high, respectively) was assessed to be low or not present in most regions.

Conservation and Restoration of Grasslands

In the last decades, much attention has been given to the conservation and restoration of biodiversity in natural and semi natural habitats, including grasslands of the Palaearctic realm and elsewhere (Brudvig, 2011; Török et al., 2018). Conservation authorities seek cost-effective ways to restore and sustain grassland biodiversity by considering theoretical findings on dispersal, species pool, community assembly rules and biodiversity patterns (Laughlin, 2014; Török and Helm, 2017). In the last years, various conservation efforts to monitor, maintain and promote grassland extent and diversity were made. This includes large national biodiversity monitoring programs (e.g., Bergamini et al., 2019), subsidies to farmers and restoration efforts. In Europe, there are many landscape-scale grassland restoration programs funded by the EU. Browsing the LIFE program database searching for themes of "Habitats-Grasslands" with the keyword "restoration measure" retained 101 projects in the 1993–2017 timeframe (European Union, 1995–2019). However, a large proportion of subsidies within the EU common agricultural policy (CAP) is still misleading as they often promote productive grasslands and do not conserve HNV grasslands and their diversity (Sutcliffe et al., 2015). A rethinking and the development of appropriate tools to reverse negative trends are urgently needed. This aspect is of particular importance in current nature conservation planning, as the European Union's CAP assigns outstanding importance to permanent grassland for species protection. Permanent grassland is an agricultural term that is generally defined as "land used by sowing or self-seeding for the cultivation of grasses or other forage plants and not used as arable land for at least five years" (Bundesamt für Naturschutz, 2014). However, the basic EU guidelines on the promotion and conservation of permanent grasslands do not only lack specific management recommendations, but do not distinguish between extensively and intensively managed permanent grasslands with regard to their impact on environmental and biodiversity protection, which to our opinion also should be considered in the revision of the CAP for the next funding period (see Pe'er et al., 2014, 2019). However, at a specific level there are various management-related instruments for achieving environmental objectives in the common European agricultural policy (e.g., agri-environmental and climate measures, organic farming and animal welfare measures; see Bundesministerium für Ernährung und Landwirtschaft, 2015).

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