WORLD GRASSLANDS AND BIODIVERSITY PATTERNS

A Report to IUCN Ecosystem Management Programme

NatureServe

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Photo: Measuring biodiversity in an alvar in eastern Ontario, Canada, 2003. Don Faber-Langendoen.

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September 2010

Don Faber-Langendoen and Carmen Josse

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Executive Summary

The European Union Directive from 2008 on the promotion and use of energy from renewable resources (referred to as "RED") states that biofuels and bioliquids cannot be produced from raw material obtained from land with high biodiversity value. These lands are defined to include, among other categories, "highly biodiverse grassland areas, including natural and non-natural grasslands." The challenge is to provide a methodology and relevant information for all Article 17(c) categories that an operator can follow to avoid these grassland areas.

To address this challenge we took the following approach:

1) Provide a comprehensive ecological definition of grasslands

2) Clarify distinctions between "natural" and "non-natural" grasslands

3) Sketch out a world classification of grasslands, using the structure of the International Vegetation Classification (IVC)

4) Use "species richness" as a measure of biodiversity, as recommended by the European Commission

5) Summarize issues regarding inclusion of both exotics and native species

6) Compile data on species richness in grasslands from around the world, from plot data summaries available in the literature

To address the first three tasks, we took the existing IVC classification, developed for only parts of the globe, and completed an outline of world grasslands. We separated grasslands into 7 formations (from Tropical Lowland Grassland, Savanna & Shrubland to Alpine Scrub, Forb Meadow & Grassland) and 55 Divisions. We briefly described each division.

To address the remaining tasks, we summarized the readily available literature (over 50 articles) on species richness by division and by ranges of plot sizes within divisions. We only accepted data where a specified unit area was provided and where all vascular species were used in the summary values. We included data from all sampled grasslands reported in the paper (we excluded non-grassland types), but in our final analysis we excluded types or data that were noted as being from heavily grazed or improved pastures or disturbed roadsides. Thus we restricted our data to good-condition grasslands.

Unit areas ranged from 0.25 m^2 to over 10,000 m^2. Given the large data gaps for some divisions, we ultimately summarized the plot species richness by three sizes that seemed practical for use within the context of RED, and because they contained sufficient data: 10–30 m^2, 31–100 m^2, and 101–1,000 m^2.

These data are first approximations of patterns of species richness for grasslands around the world. They should be interpreted cautiously because we did not have access to the original plot data.

The best data provided are at the 0.01 to 0.1 ha (or 101–1,000 m^2) range of plot sizes, based on which there appear to be formation-specific patterns. As an example, Tropical grasslands appear to be the most diverse, followed in order by Mediterranean, Temperate, Tropical Montane, and finally Cool Semi-Desert grasslands. Alpine vegetation was not well-represented. Thus, definitions of highly biodiverse grasslands may need to be specified by formation.

We were not tasked to develop the thresholds and criteria for what defines "highly biodiverse grasslands." Rather, we compiled information that can help the European Commission and others determine the feasibility of developing these criteria, to be used against a finalized grassland classification system. Nevertheless, it proved hard to find papers that consistently assessed the same area for species richness. We provide some suggestions for how a more thorough analysis might be conducted:

- Obtain raw plot data. Working with data that has already been averaged will make it hard to see how this data compares to actual field data gathered by someone making decisions for the implementation of RED.

- Ensure that data comes from sites that are considered to be in "good ecological condition," meaning avoid sites that are heavily grazed, disturbed by roadside activities, or recently established after farm abandonment, etc.

- Seek out a broader set of data within each formation to assess spatial scales of species richness, from 100 m^2 to 1,000 m^2

- Presuming some level of sufficient data, assess the most applicable species-area curve models, keeping in mind the following issues:

    - Assess potential effect of nonrandom placement of plots on species richness

    - Assess which species-area model to use (log-log or semi-log)

    - Assess whether species-area curves differ by formation

    - Based on species-area curves, determine whether some grassland types can be labeled as "biodiverse grasslands," i.e., whether there are thresholds at multiple spatial scales (or perhaps at some optimal spatial scale)

- A species-area curve may not be critical if sufficient data could be attained at the 100 m^2 or 1,000 m^2 level. But if good species-area curves can be established, they would allow for greater flexibility in the choice of plot sizes.

Introduction

Grasslands have many biodiversity values, including wildlife habitat, occurrence of rare species, intrinsic ecosystem properties of structure, function and composition, and ecosystem services such as watershed protection, grazing, and scenery. In addition, some grasslands are seen as having high biodiversity values because of their high species richness. As part of a global strategy to maintain the world's biodiversity, there is a need to ensure that these types of grasslands are not negatively impacted upon by human uses.

Why Dry Grasslands Have High Biodiversity Values

- Dry grasslands are particularly species-rich in many plant and animal groups and they thus host a proportion of Europe's biodiversity that by far exceeds their spatial coverage
- European dry grasslands are among those plant communities with the highest small-scale species densities ever recorded worldwide
- Dry grasslands are of high conservation concern as they host many endangered species and they are strongly threatened throughout Europe by many factors, such as destruction for other activities, abandonment of traditional use, afforestation, eutrophication, or invasion of neophytes
- Most of the dry grassland types fall under the Habitats directive of the European Union
- Dry grassland species have developed a wide range of interesting adaptations to their harsh environment, such as drought, high solar irradiation, lack of nutrients, instable soils, or grazing pressure
- Dry grassland are very suitable as a model system for biodiversity analyses because: their small-scale richness reaches from low to extremely high; they span very wide latitudinal, altitudinal, and pH ranges; they occur both as natural and anthropogenic communities; they comprise not only vascular plants but also bryophytes and lichens; and they typically grow in isolated patches

Jürgen Dengler, Monika Janišová, and Solvita Rūsiņa , 2008

The Policy Objective

The European Union (EU) Directive on the promotion and use of energy from renewable resources (Directive 2009/28/EG-RES-D)[1] (hereafter "RED") was passed by the European Council in December 2008. It states that biofuels and bioliquids cannot be produced from raw material obtained from land with high biodiversity value. These lands are defined as "land that is a primary forest or woodland of native species; designated areas of nature protection (protected by legislation or a relevant authority for nature protection); areas for protection of rare, threatened, or endangered ecosystems and species recognized by international agreements and those included in lists established by intergovern-mental organizations, including the International Union for the

[1] Official Journal of the European Union. 2009. Directvie 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC 5.6.2009.

Conservation of Nature (IUCN); and highly biodiverse grassland areas, including natural and non-natural grasslands."

The challenge is to provide both a methodology and relevant information for the categories included in Article 17 (3c) regarding highly biodiverse grasslands that an operator can follow to avoid them. Biofuels produced from feedstock sourced from grassland outside of these areas can then count for a respective Member State's target within the framework of RED.

Identifying the Issues

Within the overall challenge of providing a methodology and relevant information to meet the policy objectives of RED, we specifically address the challenge of defining and characterizing highly biodiverse grassland. In order to meet that challenge, a sequence of issues must be addressed:

- How are "grasslands" defined around the world?
- How are "natural" and "non-natural" grasslands defined?
- How can we classify the full range of grassland types around the world?
- How do we define "highly biodiverse grassland?"
- Will both exotics and native species be included within the definition of highly biodiverse grassland?
- Can we establish a consistent meaning for highly biodiverse grasslands around the world for both natural and non-natural grasslands?

Meeting the Challenge

To address the challenge we took the following approach:

1. Define grasslands, emphasizing differences between a land-use approach versus an ecosystem/land-cover approach

2. Provide information on distinctions between natural and non-natural grasslands, as established by the IVC and other publications

3. Sketch out a world classification of grasslands, using the structure of the International Vegetation Classification (IVC), using the "formation," "division," and "macrogroup" levels, with linkages to other widely established classification types (e.g. Braun-Blanquet classes, country-level vegetation or ecosystem publications, etc.); each type will be briefly characterized and its geographic range described—the goal at this stage is not to be definitive in classification, but to show how it can help guide policy

4. Use "species richness" as a measure of biodiversity, while noting other measures of biodiversity

5. Summarize issues regarding inclusion of both exotics and native species in measures of species richness

6. Compile a wide range of data on measures of species richness in grasslands around the world, organizing the information by IVC formation, division, and macrogroup, and provide an initial synopsis of how "highly biodiverse grasslands" might be defined; a formal analysis of the compiled data is not part of the project, but some mention will be made regarding how to develop species-area curves and identify thresholds for highly biodiverse grasslands

We were not tasked to develop the thresholds and criteria for what defines a "highly biodiverse grassland." Rather, we developed the information that can help the European Commission, via project partners, determine the feasibility of developing this information. We do provide some suggestions for how that analysis might be conducted.

World Classification of Grasslands

Defining Grasslands

Previous work by IUCN has summarized the various approaches to defining grasslands (IUCN 2009), and here we emphasize what IUCN refers to as "natural grasslands" (including semi-natural grasslands). We use a vegetation-based, ecological definition, where grassland may be defined as "land covered with herbaceous plants with less than 10 percent tree and shrub cover," and wooded grassland (or savanna) is "land covered with grassland and has 10–40 percent tree or shrub cover" (UNESCO 1973, White 1983). Other definitions allow the woody layer to have anywhere from 15 to 50% cover, as long as the ground layer has a more-or-less continuous grass or graminoid layer (e.g., White et al. 2000). As tree cover increases, it tends to shade out the grass layer. It is common to include low shrub steppe or shrubland in the broader definition (e.g., White et al. 2000), because low shrubs and herbs essentially occupy the same layer.

For other purposes, grassland is defined by its use, namely as "grazing land." Definitions of grassland as a land-use category and the associated term "rangeland" are multitude, many with specific local legal connotations. Here we emphasize the ecological definition based on the vegetation (as with the UNESCO definition above).

Spatial adjacency of grasslands and shrublands is very common in nature. Moreover, in many settings, grasslands tend to have scattered shrubs, from dwarf to midsize. This combination is more obvious where extreme climatic and edaphic conditions occur and the combination shifts to forbs and succulent shrubs (i.e., cool and warm semi-deserts).

In general the ecological explanations for the occurrence of grasslands are linked to two primary structuring forces that operate in different directions: competition for canopy space and grazing pressure (Diaz et al. 1992, in Mucina et al. 2006). Besides herbivory, rainfall, temperature, soil type, and fire are further major determinants of grassland structure and these are strongly interactive (Walker 1993, in Mucina et al. 2006).

A major subdivision of grasslands is that of tropical/subtropical versus temperate ones, and it is in the tropics where the mixture of grasslands and shrubs/trees originates an almost continuum of "open savanna" to woodland to seasonal forest, with increasing levels of tree coverage. The main environmental requirements for the existence of savanna vary across latitudes and continents, but in general they require warm temperatures year round, a strongly seasonal rainfall ranging from 300–1,800 mm, and an interaction of soils and precipitation that either allows water storage in the case of extreme conditions of evapotranspiration or, on the other extreme, have a hardpan near the surface that impedes proper drainage. Fire and herbivores are part of the natural dynamics of the savanna ecosystem. All of these factors interplay in different ways to produce various levels of density, structure, and spatial pattern of the woody component of savannas (Silva and Sarmiento 1976, Rutherford et al. 2006 and references therein).

Almost all grasslands experience some level of grazing and or burning; others are regularly mowed. We tracked the kinds of disturbances, from natural processes to human activities, to see how this might affect the biodiversity. The more intensive the human management, especially from mowing, the greater the possibility that the type will shift to a semi-natural state.

> CONCLUSION: An ecological, existing land-cover definition, as exemplified by the UNESCO approach, is used to classify grasslands, rather than a pastoral, land-use definition. The ecological approach allows us to characterize current extent and patterns of grasslands wherever they are found, whether they dominate large landscapes or occupy small localized areas.

Defining Natural and Non-Natural Grasslands

RED specifically includes both natural and non-natural grasslands. Some clarification may be needed as to what is intended. We interpret the term "grasslands" to *exclude* habitats dominated by grasses that occur in lawns, gardens, and golf courses (i.e., developed vegetation) and annual, biannual, and short-rotation grass crops and hay meadows (i.e., agricultural vegetation). These may be termed "cultural vegetation," have a growth form and composition unrelated to grasslands, and are controlled largely by human-driven factors of species introduction, selection, spraying, fertilization, plowing, etc.

Natural grasslands are dominated by native species and are largely controlled by natural processes, even if some human management occurs. These native grasslands may have been grazed for many hundreds of years, such that their historical naturalness is not easily defined (e.g., Mideast, African, Asian meadows), or they may be largely maintained by natural process of fire, native grazers, etc.

“Non-natural” grasslands is a somewhat ambiguous term, and not widely used in the literature. As used in the RED, we take it to mean grasslands that are often found in forested regions and that have been created on sites that were cleared of trees, and perhaps planted with native species or simply favored the natural grassland species on the site. They include old planted meadows that are now “naturalized” (such as those planted pre-1500s), and may include a mix of natives and more historic “exotic” (archeophytes) species that have been present for hundreds of years. The term “semi-natural” is more commonly used to describe these grasslands (Rychnovaská 1992), and they often appear quite natural.

Perhaps more distinctly semi-natural are newly formed grasslands that establish on abandoned agricultural lands or that are formed by recent invasive exotic (neophyte) species. We can distinguish these types of semi-natural grassland as “ruderal grassland.” Examples of these kinds of grasslands include *Imperata cylindrica* or *Hyparreni*a *rufa* grasslands of the tropics, and *Bromus inermis* grasslands of North America. These more “weedy” grasslands rarely contain highly biodiverse grasslands, or if they do, they may be dominated by neophyte or recent invasives that are often seen as reducing overall biodiversity value of grasslands (e.g., Lunt et al. 2007, among many). Over time, a grassland can move from one state to another, as degraded grasslands regain natural biodiversity value, or natural grassland are “pushed” into altered conditions by invasive exotics (see Table 1 in Lunt et al. 2007). Thus, we do not define “natural” or “native” grasslands as those that existed only prior to active human management. Rather it is the degree of naturalness, spontaneity of ecological processes, and historical persistence of the flora.

Despite these potential complications, the literature we consulted on grassland biodiversity quite clearly fell within the “native vegetation” (natural grasslands) except for some cases in Europe. For example, the Swiss Alps contain ancient pastures, cleared from forests centuries ago, which persist as “semi-natural” grasslands to this day (and are highly valued for other cultural reasons). Our information rarely includes data on ruderal grasslands and never on exotic-dominated grasslands.

CONCLUSION: We distinguish grassland from cultural vegetation, such as grass-dominated row crops and lawns. Within the grasslands category we include both natural grassland and semi-natural (“non-natural”) grassland, but we typically exclude more recent ruderal or exotic-dominated grasslands in our survey.

Introduction to the International Vegetation Classification

We approach the description and characterization of grasslands around the world using the International Vegetation Classification. The overall purpose of the IVC is to characterize world vegetation and ecosystems in a scientifically consistent and repeatable manner, and to use it to permit users to produce uniform statistics about ecosystem resources around the globe, facilitate interagency cooperation on ecosystem-based management issues that transcend jurisdictional boundaries, and encourage partners to work together on a common system. To achieve this goal, NatureServe has worked with a variety of partners to guide the initial development of the IVC. Information is now available on the structure and naming of the upper levels of the vegetation classification hierarchy, refined definitions for the lower, floristic levels of the hierarchy, and restructuring the classification from a content standard to a dynamic process standard (Faber-Langendoen et al. 2009, Jennings et al. 2009). Partners are now engaged in a sustained effort to build and provide this classification to users. The IVC has already been shown to provide a framework to guide development of world grassland types (Gibson 2009, Table 8.1).

Formation, Division, and Macrogroup

These three levels are the primary levels we use to develop an initial conspectus of grassland types (see Appendix A for details).

Table 1. The Main Levels of the IVC Hierarchy Used for This Report.

Hierarchy Level	Criteria	Example
L3 – Formation	Combinations of dominant and diagnostic growth forms that reflect global macroclimatic factors as modified by altitude, seasonality of precipitation, substrates, and hydrologic conditions	Temperate Grassland & Shrubland
L4 – Division	Combinations of dominant and diagnostic growth forms and a broad set of diagnostic plant taxa that reflect biogeographic differences in composition and continental differences in mesoclimate, geology, substrates, hydrology, and disturbance regimes	Great Plains Grassland & Shrubland
L5 – Macrogroup	Combinations of moderate sets of diagnostic plant species and diagnostic growth forms that reflect biogeographic differences in composition and subcontinental to regional differences in mesoclimate, geology, substrates, hydrology, and disturbance regimes	Tallgrass Prairie Grassland & Shrubland

Methods for an Initial Conspectus of World Grassland Types

We took the following steps to develop a classification:

1. We first conducted a very rapid review of literature. We assessed ecoregional patterns based on WWF (Olson et al 2001) to make sure we include all major grasslands of the world.
2. We developed comprehensive world grassland types for all formations and divisions.
3. We then developed macrogroups for all grasslands that are fairly extensive (many km^2 in area) and for which available literature could be found.
4. We developed IVC-type names, but we provide synonymy of types to literature names, so that users can see the basis for our concepts. We then developed a brief description and short geographic distribution for each division.

We summarize our primary classification results in a Table of Formation and Division units (Table 2). The grasslands classification is a basis for the assessment of where highly biodiverse grasslands are found.

Table 2. List of World Grassland Formations and Divisions, and the Literature on Species Richness Identified for Those Types. Divisions with no "key" code are in the process of being assigned one in the IVC Database.

Formation	Division Key	Division
2.A.1 Tropical Lowland Grassland, Savanna & Shrubland		
		2.A.1.Ea Central American – Caribbean Lowland Shrubland, Grassland & Savanna
		2.A.1.Eb Amazonian Shrubland and Savanna
		2.A.1.Ec Guayana Shrubland and Savanna
		2.A.1.Ed Parana Brazilian Shrubland and Savanna
		2.A.1.Ee Chacoan Shrubland and Savanna
		2.A.1.Ff West-Central African Mesic Woodland and Savanna
		2.A.1.Fg Eastern and Southern African Dry Savanna and Woodland
		2.A.1.Fh Mopane Savanna
		2.A.1.Fi Sudano Sahelian Dry Savanna
		2.A.1.Ij Indomalayan Mesic Savanna and Grasslands
		2.A.1.Lk Australian Tropical Savanna
		2.A.1.Ol Polynesian Lowland Shrubland, Grassland & Savanna

Formation	Division Key	Division
		2.A.1.Om Eastern Melanesian Lowland Shrubland, Grassland & Savanna
2.A.2 Tropical Montane Grassland, Savanna & Shrubland		
		2.A.2.Ea Tropical Andes Shrubland and Grassland
		2.A.2.Eb Caribbean and Central American Montane Shrubland and Grassland
		2.A.2.Ec Guayanan Montane Shrubland and Grassland
		2.A.2.Ed Parana Brazilian Montane Shrubland and Savanna
		2.A.2.Fe African Montane Grassland and Shrubland
		2.A.2.F4 African (Madagascan) Montane Grassland and Shrubland
		2.A.2.If Indomalayan Montane Meadow
		2.A.2.Lg New Guinea Montane Meadow
	D076	2.A.2.Oh Polynesian Montane Shrubland, Grassland & Savanna
		2.A.2.Oi Eastern Melanesian Montane Shrubland, Grassland & Savanna
2.B.2 Mediterranean Grassland & Forb Meadow		
	D021	2.B.2.Na California Grassland & Meadow
		2.B.2.Px Mediterranean Basin Dry Grassland
		2.B.2.Pc Mediterranean Basin Montane Grassland & Scrub
		2.B.1.Ea Chilean Mediterranean Scrub
		2.B.1.Fb South African Cape Mediterranean Scrub
		2.B.1.La Australian Mediterranean Scrub
2.C.1 Temperate Grassland, Meadow & Shrubland		
		2.C.1.Ea Pampas Grassland & Shrubland
		2.C.1.Eb Southern Andean Shrubland and Grassland
		2.C.1.Fc Southern African Montane Grassland
		2.C.1.La. Australian Temperate Grassland & Shrubland
		2.C.1.Lb. New Zealand Grassland & Shrubland
	D022	2.C.1.Na Vancouverian & Rocky Mountain Grassland & Shrubland
	D023	2.C.1.Nb Great Plains Grassland & Shrubland
	D024	2.C.1.Nc Eastern North American Grassland, Meadow & Shrubland

Formation	Division Key	Division
	D061	2.C.1.Nd Western North America Interior Sclerophyllous Chaparral Shrubland
		2.C.1.Ne Southeastern North American Grassland & Shrubland
		2.C.1.Pa European Grassland & Heath
		2.C.1.Pb Western Eurasian Grassland & Shrubland
		2.C.1.Pc Eastern Eurasian Grassland & Shrubland
		2.C.1.Pd Northeast Asian Grassland & Shrubland
2.C.2 Boreal Grassland, Meadow & Shrubland		
	D025	2.C.2.Na North American Boreal Grassland, Meadow & Shrubland
		2.C.2.Pa Eurasian Boreal Grassland, Meadow & Shrubland
3.B.1 Cool Semi-Desert Scrub & Grassland		
	D040	3.B.1.Na Western North American Cool Semi-Desert Scrub & Grassland
		3.B.1.Pa Eastern Eurasian Cool Semi-Desert Scrub & Grassland
		3.B.1.Pb Western Eurasian Cool Semi-Desert Scrub & Grassland
		3.B.1.Ea Patagonian Cool Semi-Desert Scrub & Grassland
4.B.1 Alpine Scrub, Forb Meadow & Grassland		
		4.B.1.Fc Southern African Alpine Vegetation
	D042	4.B.1.Na Western North American Alpine Scrub, Forb Meadow & Grassland
	D043	4.B.1.Nb Eastern North American Alpine Scrub, Forb Meadow & Grassland
		4.B.1.Pa European Alpine Vegetation
		4.B.1.Pb Central Asian Alpine Vegetation
		4.B.1.La Australian Alpine Vegetation
		4.B.1.Lb New Zealand Alpine Vegetation

A brief description and geographic range for each type is provided in Appendix B (attached spreadsheet). We did not include tundra in our assessment (North American and Eurasian). Further review of the extent of tundra grasslands is needed (e.g. see White et al. 2000).

CONCLUSION: A framework and very brief description for types of world grasslands have been achieved, with ties to common international and national lists of types. But it is still very skeletal and will need additional research to solidify grassland type concepts and ensure that it is comprehensive.

Measuring Biodiversity—Species Richness

Measures of Biodiversity

Biodiversity can be assessed at different scales. It is common to identify a) point diversity (or plot diversity) = all species and their abundance in a fixed area; b) alpha diversity—sometimes equated to plot diversity but sometimes distinguished as stand diversity, i.e., species richness and abundance across all plots within a stand; c) beta diversity—turnover of species and abundance between stands; and d) gamma diversity—the diversity of species and abundance within a landscape (Klimek et al. 2007).

In addition to the scale of biodiversity, there are various attributes of biodiversity, such as species identity and abundance, measured as species richness, evenness, dominance, or rarity. For example, Wilsey et al. (2005) distinguishes the following attributes of biodiversity:

- Species richness (the number of species found in a per unit area)
- Species evenness (the variability in species abundance)
- Simpson diversity index (a statistic that incorporates richness and evenness)
- Berger-Parker (a dominance-based measure of evenness)
- Rarity (a measure of how uncommon a species is in a specified region or jurisdiction)

Based on these attributes, a highly biodiverse grassland could mean several things:

- High point (plot) diversity or stand diversity (measured by species richness)
- High compositional diversity (measured by Simpsons, Evenness, or Berger-Parker)
- High number of endemic species (measured through biogeographical range assessments)
- High number of rare species (either rare within a study area or rare based on subnational, national, or global ratings)

In addition, highly biodiverse grassland could be assessed based on other criteria:

- Contains rare ecosystem or vegetation types (ecosystem red lists)
- High-quality condition (ecological integrity)

A recent study of various biodiversity measures by Wilsey et al. (2005) highlighted the value of species richness as a measure of biodiversity, but they noted that other measures do have important additional information. Reitula et al. (2009) report that interpretations of changes in small-scale (50 x 50 cm plots) patterns of biodiversity in semi-natural grasslands depend on whether one is assessing species richness or species evenness. For example grassland plant species richness was positively associated with present-day availability of grassland species in the surrounding landscape, whereas evenness was mainly related to the historical landscape.

Of the various other measures of biodiversity, Wilsey et al. (2005) recommend the Bergen-Parker index, because it only requires that a field team measures the abundance of the most common species (e.g., its cover or biomass) versus the total abundance. But values have not been widely reported for this measure. Species evenness is another common measure.

Species Richness

For many studies, plant species richness is an important measure of biodiversity. It is often used as a surrogate for biodiversity in general. It is relatively easy to measure, reliably estimated for extended periods throughout the growing season, and doesn't require assessing abundance. Therefore it was the chosen measure of richness for which we were asked to provide data. As noted above, it does not encompass all aspects of biodiversity, and its degree of correlation with other forms of biodiversity may vary (Leal et al. 2010). Nonetheless, it is one practical and targeted measure of biodiversity for a dominant component of grasslands being harvested for biofuels—the plants themselves.

For plant species richness, point (plot-based) diversity is the most standard method for assessing richness. Nested plot diversity estimates are preferred because they allow for generalizations of species richness across multiple spatial scales.

> CONCLUSION: For this report, we focus on plant species richness as one important measure of biodiversity.

Ecological Drivers of Grassland Biological Diversity

There are many factors that shape biodiversity (Belsky 1992, Klimek et al 2007, Veen et al. 2008, Collins et al. 1998). Briefly, these include:

- Site factors (slope, aspect, nutrient status (alkaline, acid, moist, dry))
- Grazing
- Mowing
- Fire
- Fertilization (manuring, N deposition)
- Successional dynamics
- Biome/latitudinal/evolutionary gradients

Controlling factors may not simply be switched on or off to reset diversity. Loss of richness may not always be reversible (Lunt et al. 2009).

Many studies describe how these controlling factors affect species richness with a grassland type. Thus, when compiling grassland species richness, we recorded, if provided, the species richness by these controlling factors.

> CONCLUSION: When available, we document how species richness within a grassland type varies, depending on the controlling factors (e.g., mowing, grazing, fire, and substrate).

NATIVE VERSUS EXOTIC SPECIES RICHNESS

Our study focused on natural grasslands, broadly defined as distinct from cultural vegetation, but including semi-natural grasslands. For example, all naturalized and old meadows in Europe can be considered part of this broad definition of natural grasslands. Thus included are old managed subalpine meadows that are now "naturalized" (planted or cleared for grazing pre-1500s) or where native grasslands have been so long grazed by pastoralists (hundreds of years) that their natural condition is largely shaped by that activity (e.g., Mideast, African, Asian meadows).

There are an increasing number of studies that document the relative contributions of both native and exotic or naturalized species to plant species richness. In some cases, natural grasslands have become dominated by new invasive exotic species ("neophyte"exotics), with consequent changes in their composition and ecological services. For this reason, Suttie et al. (2005) excluded *Imperata cylindrica* exotic invasive grasslands from their survey, because it is a nonpalatable grass and not native to continents where it is an aggressive invader of native grasslands.

In parts of the world (Europe, much of North America, Australia, South Africa), there is much concern about the negative effects of recent invading exotics on the condition and richness of native grasslands. Conservation-focused managers of these grassland types would not consider grasslands of exotics species with high biodiversity to be of much interest, except as sites for potential restoration. As stated by Lunt et al. (2007, p. 403), "while pastoralist communities value all palatable forage (native or exotic), conservation managers seek to promote native biodiversity and to minimize exotic species." For this reason, we tracked information on native species richness separate from exotic species richness, when provided.

> CONCLUSION: Data on plant species richness in natural grasslands is widely reported in the ecological literature, and we emphasize those types. When available, we document the proportion of species richness within a grassland type that is considered native versus exotic, because these exotics may change both the biodiversity status and ecosystems services of the grassland.

Grassland Species Richness Patterns

Method

We compiled a wide range of data on measures of species richness in grasslands around the world, organizing the information by IVC formation and division. We worked with readily available materials. The information is not comprehensive! Rather it is illustrative. Further research will turn up many more studies.

The details of each paper are provided in a spreadsheet as Appendix B, with separate tabs for "Species Richness_Temperate" and "Species Richness_Tropical."

We also summarize the availability of information for each division (see Appendix B, tab labeled "Division Descrip and Richness Sum"). Because there is no standard set of plot sizes used to characterize species richness, we established a series of typical ranges in plot size and organized the studies by these plot sizes (e.g., studies using plot sizes between 1 and 9 m^2 were recorded in the same column).

We then further reduced the information to a summary by formation. This is included in Appendix B, but is also summarized in our results below.

Summary Results of Information on Grassland Species Richness

There are no standard plot sizes that are used widely across the world when assessing grassland species richness. Plot sizes ranged from 0.25 m^2 to over 1,000 m^2. That said, there are typical ranges of plot sizes, and we used those sizes to order our studies. These sizes were 1–9 m^2, 10–30 m^2, 31–100 m^2, 101-1,000 m^2, and 1,001–10,000 m^2. We further refined our summary of species richness by focusing on the middle ranges of plot sizes:

- 10–30 m^2
- 31–100 m^2
- 101–1,000 m^2

We chose these sizes because they appeared to offer large-enough areas of sampling that some differentiation in species richness among grassland types might be expected.

Our results turned up over 50 papers on grassland species richness, but when spread across the many grassland divisions and ranges of plot sizes, the data become comparatively thin.[2] For that reason we have summarized the data at the formation level, as presented in Table 3.

These data are first approximations of patterns of species richness for grasslands around the world. They should be interpreted cautiously, because we did not have access to the

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[2] There are many more papers published on plant species richness from grassland types around the world, but we were asked to develop a summary in a short period of time, in order to determine whether the approach would be fruitful.

original plot data. Typically, a paper might provide an average (mean) species richness and standard deviation (or standard error), and perhaps a range across the set of plots. If we have three papers that describe species richness at the 0.1 ha level, and each provides an average species richness, we then took each of those averages and **we created a summary average, and report the range of the averages. Thus the ranges are quite conservative.**

There were also a number of studies in the temperate grassland that reported exceptionally high values of richness. We have reported those separately, as they appear to be outliers (Walker and Peet 1983, Ryser et al 1995).

Table 3. Summary of Species Richness by Formation. For each formation, the average shown is the average of the average richness reported across multiple studies. The very high species rich types in *2.C.1 Temperate Grassland, Meadow & Shrubland (very rich)* are separated out from the rest of the types in the formation, to illustrate their distinctive levels of very high richness.

Formation	SPECIES RICHNESS (based on Averages of Averages) Values shown are Average (range of averages)		
	10–30 m^2	31–100 m^2	101–1,000 m^2
2.A.1 Tropical Lowland Shrubland, Grassland & Savanna		40 (22–65)	64 (53–75)
2.A.2 Tropical Montane Shrubland, Grassland & Savanna	18 (13–27)	38 (21–51)	36 (21–51)
2.B.2 Mediterranean Grassland & Forb Meadow			50 (42–61)
2.C.1 Temperate Grassland, Meadow & Shrubland		35 (28 - 45)	41 (33–49)
2.C.1 Temperate Grassland, Meadow & Shrubland (very rich)	*50 (43–57)*	*49 (45–59)*	*67 (54–79)*
2.C.2 Boreal Grassland, Meadow & Shrubland			
3.B.1 Cool Semi-Desert Scrub & Grassland			23 (20–28)
4.B.1 Alpine Scrub, Forb Meadow & Grassland		36 (19–53)	68 (67–69)

We were unable to find papers for Boreal grasslands, but this is a relatively minor grassland formation. We more often lacked data for the smaller plot sizes within a formation. We only report richness values if the study included the following:

- Sometimes only natives are reported
- Sometimes only herbs (grasses and forbs) are reported; this is not ideal, but still acceptable
- Some studies provided multiple spatial scales of richness within a broad type

- Some studies provided multiple controlling factors of richness within a broad type (e.g., mowing, haying, burning)
- Some studies reported richness for both degraded and typical natural sites; we have omitted the degraded patterns here
- Some studies provided multiple subtypes of richness within a broad type (e.g., with the Great Plains grasslands, separate values are provided for shortgrass, mixedgrass, and tallgrass prairie); commonly, the drier and wetter ends were less species rich
- Some studies provided combinations of the above

The best data we have are at the 0.1 ha (or 101–1,000 m^2) range. Based on those data, there do appear to be formation-specific patterns. For example, Tropical grasslands appear to be quite diverse (as diverse as some of the very rich temperate sites), followed by Mediterranean, Temperate, Tropical Montane, and finally Cool Semi-Desert. Alpine vegetation was not well-represented, and the one large plot size study may be atypical. Thus, definitions of highly biodiverse grasslands may need to be specified by formation. Tropical grasslands might be expected to be 65+ species per 0.1 ha, Temperate and Mediterranean 45+ species per 0.1 ha, Tropical Montane grasslands 36+ species per 0.1 ha, and Cool Semi-Deserts to be 25+ species per 0.1 ha.

At the 30–100 m^2 scale, all good-condition grasslands appeared fairly equally diverse, between 35–40 species per 100 m^2 range, but the range is rather high (19 to 65). Thus it may be that 100 m^2 provides a useful standard level for assessing species richness, but using a larger 0.1 ha plot may also improve consistency in recognizing the distinction between highly biodiverse and non-highly biodiverse grasslands.

As noted above, some studies provided multiple subtypes of richness within a broad type (e.g., with the Great Plains grasslands, separate values are provided for shortgrass, mixedgrass, and tallgrass prairie macrogroups). Commonly, the drier and wetter types were less species rich than the mesic or moist type. Thus if working at the formation or division level, there will always be an inherent range of variation across a type, that may make it challenging to identify thresholds for highly biodiverse grasslands, unless one further scales the hierarchy.

Conclusions on Species Richness Patterns for Highly Biodiverse Grasslands

We were not tasked to develop the thresholds and criteria for what defines a "highly biodiverse grassland." Rather, we developed the information that can help the European Commission determine the feasibility of developing this information. We were able to obtain a wide variety of studies from around the world. Our data suggest that there may be at least some formation-level differences among grasslands.

Still, it was hard to find papers that consistently assessed the same area for species richness. We do provide some suggestions for how that analysis might be conducted:

- Obtain raw plot data. Working with data that have already been averaged makes it hard to see how these data will correspond to actual field data gathered by a team seeking to provide information on biofuels policies.

- Ensure that data come from sites that are considered to be in "good condition." That is, avoid sites heavily grazed, disturbed by roadside activities, early successional after farm abandonment, etc.

- Seek out a broader set of data within each formation to assess spatial scales of species richness, from 100 m^2 to 1,000 m^2. It may be that "highly biodiverse" grassland can be defined relative to a formation (i.e., a highly biodiverse alpine grassland may have different thresholds for highly biodiverse grassland than a tropical grassland).

- Presuming some level of sufficient data, assess the most applicable species-area curve models, keeping in mind the following issues:

  - Assess potential effect of nonrandom placement of plots on assessing species richness

  - Assess which species-area model to use (log-log or semi-log)

  - Assess whether species-area curves differ by formation

  - Based on species-area curves, determine whether there are multiple spatial scales of richness that qualify for the label of "biodiverse grassland," or perhaps at some optimal spatial scale.

- A species-area curve may not be critical if sufficient data could be attained at the 100 m^2 or 1,000 m^2 level. But if good species-area curves can be established, they would allow for greater flexibility in the choice of plot sizes when evaluating species richness of grasslands.

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Appendix A. The International Vegetation Classification

The overall purpose of the International Vegetation Classification (IVC) is to characterize world vegetation and ecosystems in a scientifically consistent and repeatable manner, and to use it to facilitate uniform statistics about ecosystem resources around the globe, facilitate interagency cooperation on ecosystem-based management issues that transcend jurisdictional boundaries, and encourage partners to work together on a common system. To achieve this goal, NatureServe has worked with a variety of partners to guide the initial development of the IVC. A recent release of a revised federal vegetation standard in the U.S. (FGDC 2008) has increased support for the system in that country; adoption of the hierarchy in Canada has begun to facilitate integration of Canadian types at multiple scales; and applications in Latin America and Africa have spurred on continental development of units. Information is now available on the structure and naming of the upper levels of the vegetation classification hierarchy, refined definitions for the lower, floristic levels of the hierarchy, and restructuring the classification from a content standard to a dynamic process standard (FGDC 2008, Jennings et al. 2009). Partners are now engaged in a sustained effort to build and provide this classification to users.

Guiding Principles

(modified from FGDC 2008)

- Develop a scientific, standardized classification system, with practical use for conservation and resource management.
- Classify existing vegetation—the plant cover, or floristic composition and vegetation structure, documented to occur at a specific location and time, preferably at the optimal time during the growing season. This standard does not directly apply to classification or mapping of potential natural vegetation.
- Classify vegetation on the basis of inherent attributes and characteristics of the vegetation structure, growth form, species, and cover, emphasizing both physiognomic and floristic criteria.
- Base criteria for types on ecologically meaningful relationships; that is, abiotic, geographic, and successional relations help organize vegetation types and levels.
- The upper levels of the IVC are based primarily on the physiognomy (growth form, cover, structure) of the vegetation (not individual species), lower levels are based primarily on floristics (species composition and abundance), and mid levels are based on a combination of vegetation criteria and abiotic factors.
- Describe types based on plot data, using publicly accessible data when possible.
- Modify the classification through a structured peer-review process. The classification standard shall be dynamic, allowing for refinement as additional information becomes available.
- Facilitate linkages to other classifications and to vegetation mapping (but the classification is not a map legend).

An introduction to the revised hierarchy, in a U.S. context, is available in Faber-Langendoen et al. (2009). Criteria for each level of the hierarchy are provided in Table 1. An example of the revised hierarchy structure is provided in Table 2. Development of the IVC reflects international input (Faber-Langendoen et al. 2008).

Table 1. Summary of Criteria and Rationale for the Natural Vegetation Hierarchy.

Hierarchy Level	Criteria
Upper: Physiognomy plays a predominant role	
L1 – Formation Class	Broad combinations of general dominant growth forms that are adapted to basic temperature (energy budget), moisture, and/or substrate or aquatic conditions
L2 – Formation Subclass	Combinations of general dominant and diagnostic growth forms that reflect global macroclimatic factors driven primarily by latitude and continental position, or that reflect overriding substrate or aquatic conditions
L3 – Formation	Combinations of dominant and diagnostic growth forms that reflect global macroclimatic factors as modified by altitude, seasonality of precipitation, substrates, and hydrologic conditions
Middle: Both floristics and physiognomy play a significant role	
L4 – Division	Combinations of dominant and diagnostic growth forms and a broad set of diagnostic plant taxa that reflect biogeographic differences in composition and continental differences in mesoclimate, geology, substrates, hydrology, and disturbance regimes
L5 – Macrogroup	Combinations of moderate sets of diagnostic plant species and diagnostic growth forms that reflect biogeographic differences in composition and sub-continental to regional differences in mesoclimate, geology, substrates, hydrology, and disturbance regimes
L6 – Group	Combinations of relatively narrow sets of diagnostic plant species (including dominants and co-dominants), broadly similar composition, and diagnostic growth forms that reflect biogeographic differences in composition and sub-continental to regional differences in mesoclimate, geology, substrates, hydrology, and disturbance regimes
Lower: Floristics plays a predominant role	
L7 – Alliance	Diagnostic species, including some from the dominant growth form or layer, and moderately similar composition that reflect regional to subregional climate substrates, hydrology, moisture/nutrient factors, and disturbance regimes
L8 – Association	Diagnostic species, usually from multiple growth forms or layers, and more narrowly similar composition that reflect topo-edaphic climate, substrates, hydrology, and disturbance regimes

Table 2. Example of the International Vegetation Classification.

Revised Hierarchy: Natural Vegetation	Example (only common names shown)
Upper	
Level 1 – Formation Class	Shrubland & Grassland
Level 2 – Formation Subclass	Temperate & Boreal Shrubland & Grassland
Level 3 – Formation	Temperate Grassland & Shrubland
Middle	
Level 4 – Division	Great Plains Grassland & Shrubland
Level 5 – Macrogroup	Tallgrass Prairie Grassland & Shrubland
Level 6 – Group	Northern Tallgrass Prairie
Lower	
Level 7 – Alliance	Big Bluestem – Indian grass Grassland
Level 8 – Association	Big Bluestem – Indian grass / Gayfeather Grassland

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Appendix B. Classification Descriptions and Details of Species Richness Information

[See attached spreadsheet, "World Grassland & Biodiversity Patterns_IVC Grassland Types and Species Richness.xls."]