THE INTEGRATED PLANT RECORD VEGETATION ANALYSIS: INTERNET PLATFORM AND ONLINE APPLICATION

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Abstract. The Integrated Plant Record vegetation analysis (IPR vegetation analysis) is a semi-quantitative method that has been developed to reconstruct Cenozoic zonal vegetation based on the fossil leaf, fruit, and pollen record, i.e., the integrated plant record. To date, thousands of taxa have been scored and more than 300 fossil and modern plant sites have been evaluated by this method. Such huge amounts of data can be handled easily and made widely available only by a sophisticated, automated working application. The internet platform www.iprdatabase.eu provides an interactive database of scored taxa, localities, and a template for the evaluation of further plant assemblages, whether fossil or modern. Moreover, the computerised application allows changing classification parameters, directly editing synonyms and typographical errors, as well as scoring taxa within formerly uploaded datasets. To keep the database operational, the abovementioned inputs are possible only under an authorised access to the application.

■ IPR-vegetation analysis, database, Cenozoic, fossil, living, plant, World Wide Web

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Introduction

The Integrated Plant Record vegetation analysis (IPR-vegetation analysis) was first introduced by Kovar-Eder and Kvaček (2003). Since then it has proven itself as an essential tool for reconstructing zonal plant cover and palaeoenvironments in the Cenozoic. It has been applied to more than 300 fossil and modern sites, integrating foliar, carpological and pollen data of thousands of taxa (Jechorek, Kovar-Eder and Kvaček 2004, Kovar-Eder et al. 2006, Kovar-Eder et al. 2008, Teodoridis et al. 2009, Teodoridis 2010, Kvaček et al. 2011, Jacques et al. 2011, Teodoridis et al. 2011). In the latter publication the IPR-vegetation analysis was applied to modern vegetation of SE China (Mt. Emei, Longqi Mt., Meili Snow Mt.) and Japan (Shirakami Sanchi, Mt. Fuji, Nara, Yokohama, Yakushima Island) to test whether it properly reflects plant sociological classification (Teodoridis et al. 2011). This study successfully tested the approach by cluster analysis. The enormous datasets that have been produced since the introduction of this method can be handled effectively and made accessible to the scientific public only by providing an open access internet platform. This includes an information website, an automated working database of the fossil taxa, of modern taxa, and plant localities, and a calculation tool to apply the IPR-vegetation analysis effectively.

Here, we introduce the internet platform for open access and automatised data-processing for the IPR-vegetation analysis and we compare the approach to other methods focusing on vegetation reconstruction.

The IPR-vegetation analysis – brief methodological description

The IPR-vegetation analysis is a semi-quantitative method developed by Kovar-Eder and Kvaček (2003) to assess zonal vegetation based on the fossil plant record (leaf, fruit, and pollen assemblages). It attempts to incorporate taxonomy, physiognomy, and autecological properties of Cenozoic plants as an objective assessment of the fossil vegetation (see Kovar-Eder and Kvaček 2007, Kovar-Eder et al. 2008). Zonal and azonal plant elements are assigned to thirteen basic taxonomic-physiognomic groups, termed components, defined to reflect key ecological characteristics of an assemblage (Kovar-Eder and Kvaček 2003, 2007, Jechorek and Kovar-Eder 2004, Kovar-Eder et al. 2008). Most recently, Teodoridis et al. (2011) render more precisely the taxonomic-physiognomic grouping: defined were the conifer component (CONIFER), broad-leaved deciduous component (BLD), broad-leaved evergreen component (BLE), sclerophyllous component (SCL), legume-like component (LEG), zonal palm component (ZONPALM), arborescent fern component (ARBFERN), dry herbaceous component (D-HERB), mesophytic herbaceous component (M-HERB). Azonal components, i.e., azonal woody component (AZW), azonal non-woody component (AZNW) and aquatic component (AQUA). The component PROBLEMATIC TAXA includes elements with uncertain taxonomic-physiognomic affinity (Tab. 1). For further analysis, all taxa (but not their abundances) of every single assemblage have to be assigned to those components and their relative

Table 1. Overview of the taxonomic and physiognomic groups defined for the IPR-vegetation analysis and their physiognomic descriptions.

TAXONOMIC-PHYSIOGNOMIC COMPONENTS		PHYSIOGNOMIC DESCRIPTION
ZONAL	CONIFER COMPONENT (CONIFER)	Zonal and extrazonal conifers. For example, *Cunninghamia, Abies, Picea*, and *Tsuga*.
	BROAD-LEAVED DECIDUOUS COMPONENT (BLD)	Zonal broad-leaved deciduous woody angiosperms. Leaf-size class microphyll (2.25-20.25 cm^2), notophyll (20.25-45 cm^2), or mesophyll (45-182.2 cm^2) sensu Webb (1959), texture thin, usually not entire-margined (Kovar-Eder et al. 2008, Fig. 3A).
	BROAD-LEAVED EVERGREEN COMPONENT (BLE)	Zonal broad-leaved evergreen woody angiosperms. Leaf-size class microphyll, notophyll, or mesophyll – see leaf size template, texture coriaceous, usually entire-margined, revolute, erose, or inconspicuously (often sparsely) toothed. The resolution of the BLE component is higher in floras with leaf cuticle preserved, which allows a differentiation of the families with uniform leaf morphology (e.g., Lauraceae) to the specific level. Without preserved cuticle, the resolution of this component should be less accurate (Kovar-Eder et al. 2008, Fig. 3B).
	SCLEROPHYLLOUS COMPONENT (SCL)	Zonal sclerophyllous woody angiosperms. Leaf-size class nanophyll to microphyll (0.25-2.25 cm^2 sensu Webb 1959, lower end of leaf size range) – see leaf size template; texture thick, toothed, often with spinose teeth (Kovar-Eder et al. 2008, Fig. 3C), or entire margined.
	LEGUME-like COMPONENT (LEG)	Woody angiosperms with legume-like folige. Leaf size class (of leaflets) leptophyll (<0.25 cm^2 sensu Webb 1959) or nanophyll, that is, the lower end of microphyll size range; mostly entire margined or inconspicuously toothed (Kovar-Eder et al. 2008, Fig. 3D).
	ZONAL PALM COMPONENT (ZONPALM)	Zonal palms, e.g., *Phoenicites borealis* and *Phoenix hercynica*.
	ARBORESCENT FERN COMPONENT (ARBFERN)	Zonal arborescent ferns.
	DRY HERBACEOUS COMPONENT (D-HERB)	Zonal angiosperm xeric herbs characteristic of open woodlands and grasslands, including dry zonal non-woody elements, e.g., monocots, ferns and horsetails.
	MESOPHYTIC HERBACEOUS COMPONENT (M-HERB)	Zonal angiosperm mesophytic herbs characteristic of mesophytic forest understorey, including zonal non-woody elements, e.g., monocots, ferns, horsetails and lycopods.
AZONAL	AZONAL WOODY COMPONENT (AZW)	Azonal woody conifers and angiosperms, e.g., *Taxodium*, *Glyptostrobus*, partly *Acer tricuspidatum*, *Salix*, *Populus*, *Avicennia*, and *Calamus daemonorops.*
	AZONAL NON-WOODY COMPONENT (AZNW)	Azonal non-woody elements characterized by herbaceous helophytes as monocots, ferns, horsetails and lycopods, e.g., *Cladium*, *Cladiocarya* (Cyperaceae), and *Decodon* (Lythraceae).
	AQUATIC COMPONENT	Aquatic plants including non-rooted hydrophytes, e.g., *Salvinia*, *Nuphar*.
PROBLEMATIC TAXA		These elements cannot be assigned to the above mentioned groups. They are included as problematic taxa.

proportions have to be calculated. To characterise zonal vegetation, the following proportions of components are regarded as relevant: (a) the proportion of the BLD, BLE, and SCL+LEG components of zonal woody angiosperms, where "zonal woody angiosperms" means sum of BLD+ +BLE+SCL+LEG+ZONPALM+ARBFERN components; (b) the proportion of the ZONAL HERB (D-HERB+M-HERB) component of all zonal taxa, where "zonal taxa" means sum of the CONIF+BLD+BLE+SCL+LEG+ ZON-PALM+ARBFERN+D-HERB+M-HERB components.

The following six zonal vegetation types have been distinguished (Kovar-Eder and Kvaček 2007, table 2; Kovar-Eder et al. 2008, table 4): zonal temperate to warm-temperate broad-leaved deciduous forests (broad-leaved deciduous forests "BLDF"), zonal warm-temperate to subtropical mixed mesophytic forests (mixed mesophytic forests "MMF"), zonal subtropical broad-leaved evergreen forests (broad-leaved evergreen forests "BLEF"), zonal subtropical, subhumid sclerophyllous or microphyllous forests (subhumid sclerophyllous forests "ShSF"), zonal xeric open woodlands (open woodland), and zonal xeric grasslands or steppe (xeric grassland). Recently, Teodoridis et al. (2011) additionally defined ecotones between the BLEF and MMF and the BLDF and MMF (Table 2).

Strengths and weakness of the IPR-vegetation analysis

As zonal vegetation is important for climate reconstruction and modeling, the IPR-vegetation analysis is designed to assess that vegetation. It focuses on presumably zonal elements to obtain a picture of mesic vegetation. It explicitly excludes azonal taxa, which have been demonstrated to distort the physiognomy of zonal vegetation (e.g., Parschlug – Kovar-Eder et al. 2004, Royer et al. 2009). Ten zonal taxa are regarded as a minimum to perform this method. The reliability of the results increases with increasing number of zonal taxa preserved. One main advantage is the possibility to employ the analysis independently for different organ assemblages, i.e., leaf, seed and fruit, pollen and spores, and potentially wood, thus taking advantage of the complementary information offered by different sources. Another key advantage is that changes in autecology that may occur over time can also be accounted for by different scorings of the same taxon at sites of different age. Such autecological adaptions, e.g., in *Cercidiphyllum* and *Zelkova* (Kovar-Eder et al. 1998, Denk and Grimm 2005), may be related to climate change (Kvaček 2007). The taxa scores therefore are not necessarily static. The IPR-vegetation analysis can be applied to single plant localities, regardless whether they yield only a leaf, fruit or pollen assemblage or different plant organ assemblages. The results provide a picture of the local mesic vegetation. If there are several sites almost equivalent in age, then zonal vegetation of a wider region can be reconstructed and the results visualised by applying a mapping program (Jechorek and Kovar-Eder 2004, Kovar-Eder et al. 2006, Kovar-Eder et al. 2008). The scoring for the IPR-vegetation analysis is simple and no additional statistical methods or support of sophisticated statistical programs are required. Although the fossil record is usually richer for azonal (mainly wetland) taxa than for zonal or extrazonal ones, the methodological development towards assessing wetland vegetation lags behind and this deficiency is one of the authors' future goals.

Vegetation reconstruction methods in comparison

A widespread and the earliest vegetation reconstruction method is the phytosociological approach (e.g., Heer 1855, Saporta and Marion 1878, Saporta 1881, Kirchheimer 1957). In this syntaxonomical concept, palaeoabiotic factors (e.g., substrate and trophy characters, groundwater table, salinity, etc.) are also considered to different degrees. In this method, several palaeophytocenological markers are usually selected based on their abundance, physiognomical and taxonomical character on this basis the defined palaeovegetation units (including their nearest living relatives (NLRs) environmental datasets) have been correlated to suitable extant vegetation units and/or subunits. Mai (1995, p. 498--603) presented most of the published vegetation types and their synonyms, thus providing a detailed overview of zonal and azonal phytosociological units in current use for the Paleogene and Neogene of Europe. In contrast, the IPR-vegetation analysis is designed to indicate major zonal vegetation types, i.e., BLDF, MMF, BLEF, etc. that are

Table 2. Adapted scheme of the zonal vegetation types, as defined by percent of zonal woody angiosperms and zonal herbs (modified after Teodoridis et al. 2011).

Vegetation type	Zonal woody components			Zonal herbaceous components
	BLD	BLE	SCL + LEG	MESO + DRY HERB
Broad-leaved decidous forests "BLDF"	> 80 %			≤ 30 %
Ecotone "BLDF" / "MMF"	75–80 %	< 30 %	< 20 %	< 30 %
Mixed mesophytic forests "MMF"	< 75 %			
Ecotone "MMF" / "BLEF"		30–40 %		
Broad-leaved evergreen forests "BLEF"		> 40 %	(SCL + LEG) < BLE	< 25 %
Subhumid sclerophyllous forests "ShSF"			≥ 20 %	< 30 %
Xeric open woodlands		< 30 %	≥ 20 %	30–40%; MESO HERB > DRY HERB up to 10 % of all zonal herbs
Xeric grasslands or steppe		< 30 %		≥ 40 %

reflected in fossil assemblages. The analysis does not consider abundances of taxa and abiotic factors are not differentiated beyond the discrimination of zonal versus azonal taxa.

Another common method that can help to interpret the structure of an ancient plant cover is a geoelement analysis. This approach has been methodologically derived from a phytogeographical approach and has been used to evaluate and show the migration and extinction of fossil taxa in the Paleogene and Neogene (e.g., Unger 1847, Heer 1855, 1859; Ettingshausen 1851, 1869, 1885; Mai 1995, Kvaček et al. 2011). This method analyses the habitat ranges of the most similar relatives (MSRs) of fossil taxa and clusters them into several defined groups, i. e. elements and/or subgroups, such as tropical-subtropical elements (A), holarctic elements (B) and others (C) (sensu Mai 1995, p. 239–240). The proportion of the defined geoelements can indicate the general vegetation character of a fossil assemblages based on the representation of the most abundant geoelement. Kvaček et al. (2011) noted an almost identical percentage proportion of the geoelements A and B (36 % vs. 59%) and percentages of the BLE and BLD components (35% vs. 52 %) sensu the IPR-vegetation analysis in the mastixioid flora of Arjuzanx (France). This fact can be simply explained by a similar methodological background of both methods: (1) to some degree corresponding taxonomic-physiognomic definitions of the geoelements A and B and the BLE and BLD components in the IPR-vegetation analysis and (2) the quantitative analysis.

Both the phytosociological approach and the geoelement analysis are weakly empirical methods, whereas the IPR-vegetation analysis includes botanical, sociological, and ecological input/information as well as quantitative evaluation.

A relatively new method is the "reconstruction of vegetation transects" developed by Bertini and Martinetto (2008, 2011). It was first applied on selected Messinian to Piacenzian floras from North and Central Italy. This method also evaluates an integrated fossil plant record and distinguishes physiognomic-taxonomic scoring parameters that are similar to the IPR-vegetation analysis such as azonal, zonal, extrazonal habitats, leaf type categories, growth forms. In addition, and differing from the latter analysis, it includes pollination types (Bertini and Martinetto. 2011, tables 2, 3). As opposed to the IPR-vegetation analysis, this new method considers "representative taxa" defined by their appropriately weighted abundance-percentage datasets. Incorporating the abundance factor into reconstructions of the fossil plant cover (which also reflects standard geobotanical methods) can help to more closely and reliably correlate hypothetical fossil azonal and zonal vegetation types to suitable living vegetation units. As mentioned above, the IPR-vegetation analysis excludes taxa abundances because they are usually strongly biased by taphonomic factors that differ usually strongly among the organ assemblages (leaves versus fruits and seeds versus pollen) – Kovar-Eder et al. (2008, p. 109). The application of the IPR-vegetation analysis on empirically (botanically) defined modern vegetation units from SE China and Japan, including the cluster analysis of the results, have proved that no significant differences exist between empirically defined vegetation types that consider abundances and the vegetation types predicted by the IPR-vegetation analysis (Teodoridis et al. 2011).

Martinetto and Vassio (2010) recently developed a special quantitative vegetation reconstruction method called the "Plant Community Scenarios" focusing only on carpodeposits (sensu Gee 2005). This method makes use of the CENOFITA 1.2 database (Martinetto and Vassio 2010). It has been introduced and tested for the flora of Ca' Viettone, Italy. As the "reconstruction of vegetation transects" method, several scoring groups are applied such as different leaf type categories, plant habitus and ecology. Contrary to all the other methods, this one includes tentative corrections for taphonomical biases induced by different size and production rates of plant parts (Martinetto and Vassio 2010, tables 2, 3).

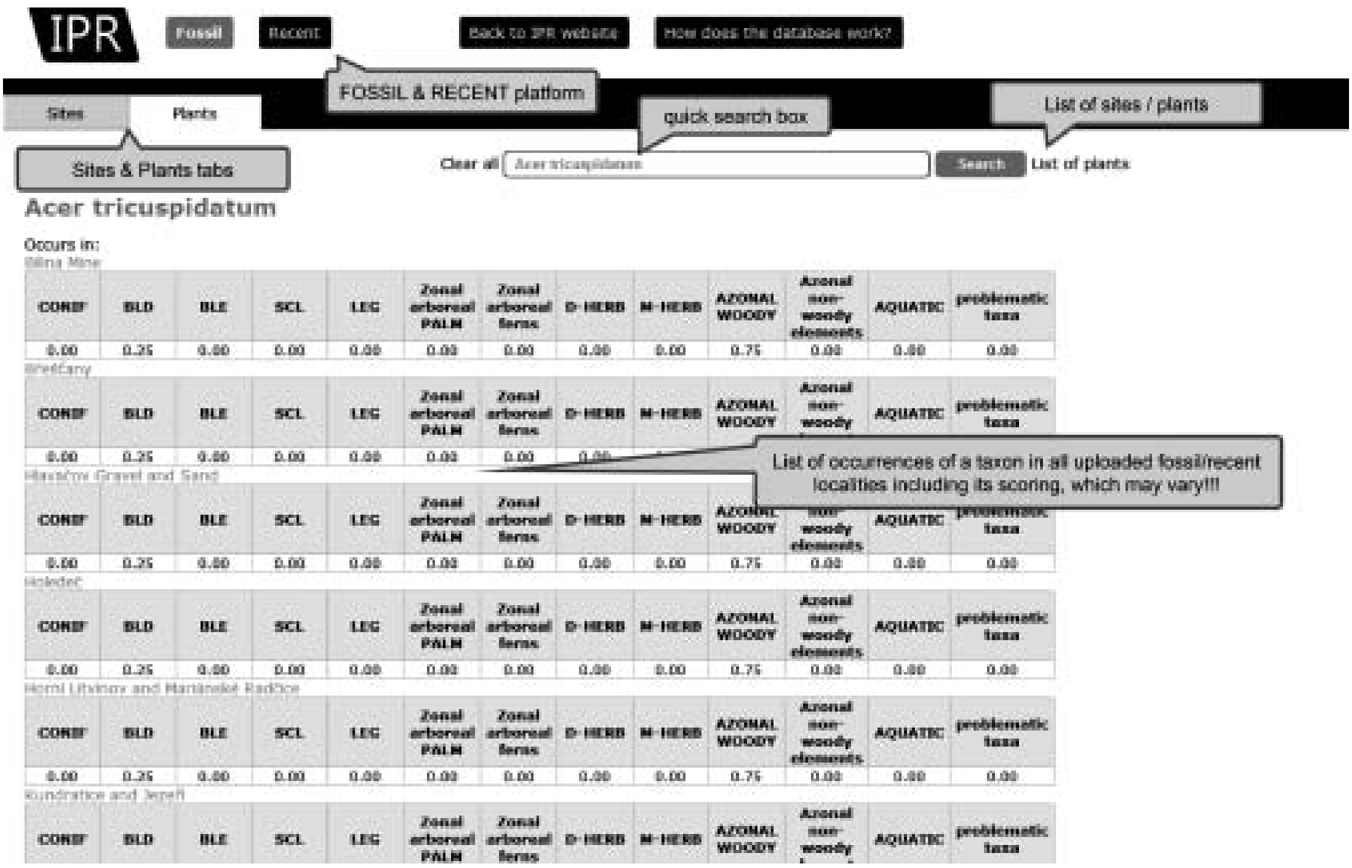
The IPR-vegetation analysis internet platform

The website and database for the IPR-vegetation analysis is freely accessible under www.iprdatabase.eu. The database yields two independently working platforms, i.e., FOSSIL and RECENT, and provides an evaluation template with formulas to calculate relevant component percentages. The FOSSIL platform includes fossil IPR-vegetation analysis datasets that cover the stratigraphical interval from Eocene to Pliocene. The RECENT platform includes modern taxa to assemble comparative IPR-vegetation datasets for living vegetation. So far in the latter, taxa from China and Japan are included (scored for the studies of Teodoridis et al. (2011). Both platforms show the same inner structure and working style to optimise user-friendliness. The databases can be searched in two different ways. The first is a "quick search" displayed on the website top. After entering the first letter, an alphabetical offering list of all taxa and/or sites (in Plants Bookmark or Sites Bookmark) starting with this letter appears for selection. Clicking on the selected name of a taxon will display all the scorings at the different sites (text-fig. 1). Note that the scores may differ between the sites (see above). Clicking on the selected site name will upload the complete IPR-vegetation analysis result (text-fig. 2). The second way to search within the database is to use the switch "list of plants/list of sites" located on the right side of the "quick search" box. Clicking on this switch, a list of taxa/sites already included in the database will appear in alphabetical or geographical (by country) order. Similar to the quick search, after the selection of a taxon and/or site, additional relevant datasets will be shown. The button "Clear all" clears the "quick search" box for the next attempt. Additional information containing detailed taxonomical and physiognomical description and autecology of taxa derived from free websites is linked to relevant living taxa and is available within the RECENT platform.

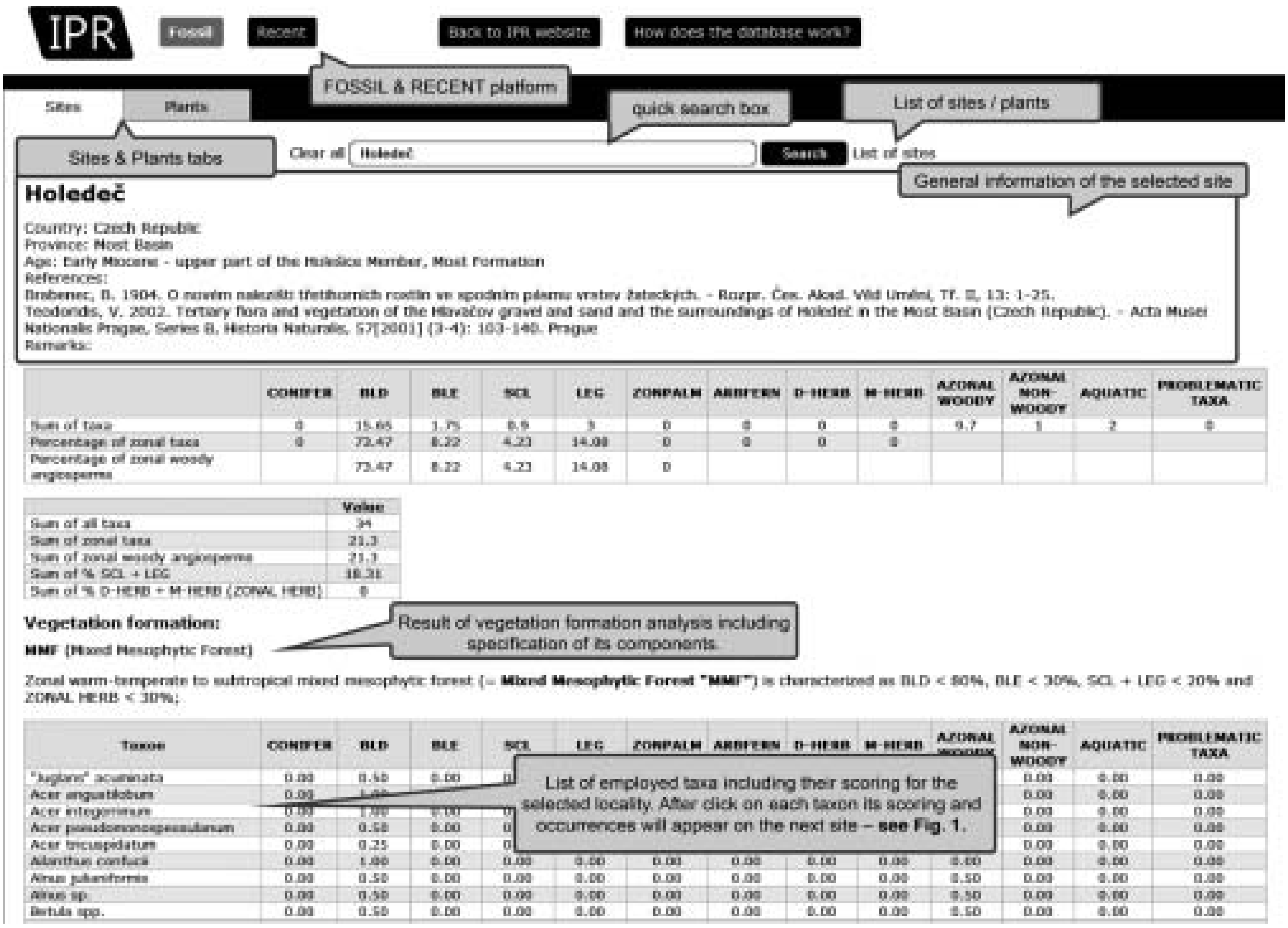
Other practical features of the internet platform are its immediate ability to change classification parameters or to directly edit synonyms, typographical errors and taxa scoring within uploaded IPR-vegetation analysis datasets. To keep the database operational, the mentioned inputs are possible only under an authorised database access.

Technical background

Raw datasets (taxa scorings) are inputted by the user into a locked "score list template" and saved as a MS Excel sheet. Mandatory fields (marked by *) include taxa scores,



Text-fig. 1. “Plant screen” scheme of complete results of the IPR-vegetation analysis derived from the database.



Text-fig. 2. “Site screen” scheme of complete results of the IPR-vegetation analysis derived from the database.

geographical information (country, locality/site), stratigraphy and references quoted, e.g., original floristic studies, etc. The mandatory items are important for further "internal" database processes (there are criteria for "internal" classification of the studied objects). A completed score list template is handled by a Visual Basic macro, which saves the file as a CSV file (a common database-friendly format). The macro handler also adjusts the input datasets into a proper format, removing invalid and obvious typological symbols). Afterwards, the CSV file is handled by a PHP import script, which imports it into the final MySQL database. The database application is powered by a combination of PHP (scripting language) and MySQL (relational database management system). It also uses the jQuery technology (a Java Script library), as well as styling by CSS (Cascading Style Sheets) and processing queries by AJAX (Asynchronous JavaScript and XML). Thanks to those technologies, the "online database" page does not need to be reloaded every time a query is processed.

IPR-vegetation analysis datasets input

The process of data input is explained here in several steps: (1) Download the scorelist template (Appendix). (2) Fill all mandatory items in the heading of the score list (marked by *). Additional information, such as province/ state and remarks quoted, are warmly welcome. Note that suffixes behind the locality names, i.e. "-P", "-L", "-F", "-X" represent pollen, leaf, and carpological or xylotomic datasets, respectively. A locality name without a suffix denotes a fossil record of leaves, seeds and fruits, and pollen. (3) Add the taxa and respective scorings into the template and save the data in the standard MS Excel format (*.xls,*. xlsx). (4) Send the file/files to the administrator of the website (i.e. the first author) and your datasets will appear within the IPR-vegetation analysis internet platform in a timely manner.

Perspectives of the IPR-vegetation analysis internet platform

The open access internet platform presented here is a useful tool to effectively perform the IPR-vegetation analysis. The authors of the database intend to put the most relevant fossil and modern IPR-vegetation results into the database in the very near future. Moreover, datasets from new IPR-vegetation analysis studies, whether fossil or modern, are welcome. With an increasing number of data sets, the database will develop and achieve its full-working state, improving the IPR-vegetation analysis to reconstruct Cenozoic zonal vegetation.

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Appendix. Score list template for the IPR-vegetation analysis database.

* Country:	
Province / State:	
* Locality / Site:	
* Age / Stratigraphy:	
* References:	
Remarks:	

* mandatory items

Taxon	TAXONOMIC-PHYSIOGNOMIC COMPONENTS / GROUPS													
	ZONAL									AZONAL			PROBLEMATIC TAXA	
	CONIFER	BLD	BLE	SCL	LEG	ZONPALM	ARBFERN	D-HERB	MHERB	AZONAL WOODY	AZONAL NON-WOODY	AQUATIC		
														0.00
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