Pladies platform: Technical description of the database structure

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Abstract

Background

Digitising and aggregating local floristic data is a critical step in the study of biodiversity. The integrative web-based platform Pladies, designed to cover a wide range of data on vascular plants, was recently developed in the Czech Republic. The combination of occurrence data with species characteristics opens many opportunities for data analysis and synthesis.

New information

This article describes the relational structure of the Pladies database service (PladiesDB) and the context of the platform architecture. The structure is relatively complex, as our goal was to cover: (i) species occurrence records, including their management, validation and export of revised species distribution maps, (ii) data on species characteristics with quality control tools using defined data types and (iii) separate user interfaces (UI) for
professionals and the general public. We discuss the approaches chosen to model individual elements in PladiasDB and summarise the experience gained during the first five years of operation of the Pladias platform.

Keywords
botany, Czech Republic, database, flora, occurrence, plant, relational database model, species, trait, tree hierarchy, vegetation

Introduction
A new botanical database platform called Pladias has recently been established in the Czech Republic. It aggregates data on spontaneously occurring vascular plants, including species occurrence records from a dozen institutional data providers and hundreds of scientists and hobby botanists (Wild et al. 2019), data on plant characteristics and data on vegetation types, making it an effective tool for botanical syntheses in Central Europe (Chytrý et al. 2021). Pladias has been extensively used by the domestic botanical community during its five years of existence and became the main source of information about Czech flora. It continues to be filled by individual species occurrence records as well as batch imports from co-operating institutions. A clone of this database for bryophytes and lichens has been created and other clones are in preparation. Here, we describe the database structure to support further deployment. Wild et al. (2019) provides a more detailed introduction to the taxonomic approach, record validation mechanism and workflow for creating species distribution maps.

The Czech Republic has a long history of botanical research (Danihelka et al. 2017) and an active community of scientists, nature conservationists and hobby botanists. The plant diversity of the country is described in flora monographs (Hejný and Slavík 1988 et seq.), identification keys (Kubát et al. 2002, Kaplan et al. 2019), a plant checklist (Danihelka et al. 2012) and a vegetation monograph (Chytrý et al. 2007 et seq.). Against this background, we aimed to develop a national platform for botanical data management, based on local needs and context.

The creation of biological databases is a relatively common component of scientific projects, but it is often associated with subsequent problems. More than half of core biological databases face financial difficulties (Merali and Giles 2005). In addition to financial sustainability, other issues include staffing and community anchoring, i.e. whether the tool has established itself amongst users and whether it can continue to perform the required functions.

In designing the Pladias database, we considered the following key elements:

• the interoperability of species occurrence records, data on species characteristics and vegetation data;
• the ability to work dynamically with a hierarchical system of taxa to transfer values (e.g. if a species has only one subspecies in the Czech Republic, but data are collected for only one of these two hierarchical ranks);
• a unified, centrally managed taxon checklist allowing direct use of data for analysis, without requiring conversions between taxon concepts;
• optimisation for plant data at the expense of extensibility to other taxa;
• preservation of the history of changes in database records;
• consistent use of open-source technologies to ensure long-term financial sustainability.

Some of these design requirements differ from the principles accepted in the Biodiversity Information Standards data model (Access to Biological Collection Data Task Group 2007, TDWG; Kennedy et al. 2006) and articulated by Patterson et al. (2008). In particular, during the Pladias development, we intentionally did not adhere to the Inclusive principle (ability to cover all forms of life), Concept-capable principle (parallel taxon concepts that are simultaneously valid or not invalidated) and Distributed organisation principle, which concerns the implementation of data storage. The advantages and disadvantages of this approach are commented below. If data are shared in global databases aggregating biodiversity data in the future, it will be necessary to add an export module mapping internal structures to standardised formats of Darwin Core. However, we have not yet proceeded with this task due to the complexity of approaches to sharing plant occurrence data by different partners in the Czech Republic.

The aim of this article is to describe the internal structure of PladiasDB and to identify and discuss specific solutions to problems commonly encountered in biodiversity databases. We focus on the PladiasDB data schema, which is an expression of the general concept of the database and can serve as inspiration for further work.

Project description

Study area description: Database of botanical biodiversity at the national scale (Czech Republic).

Design description: The Pladias platform consists of several interconnected services designed as a web application. The public interface is based on the Nette framework (PHP) and is available at https://pladias.cz (Fig. 1). The interface for data management and editing by experts was created in the Play! framework (Java/Scala) and is available at https://pladias.ibot.cas.cz (Fig. 2). The data storage, PladiasDB, is a PostgreSQL relational database supplemented by the PostGIS extension, which allows it to work competently with spatial data. Spatial information is published using standard protocols, such as Web Map Service (WMS) or Web Feature Service (WFS). Two instances of Geoserver, one public and one private, are involved to facilitate access to restricted data on the distribution of rare species. An overview of the Pladias platform architecture is provided in Fig. 3. The public interface uses several front-end libraries, notably OpenLayers, Bootstrap and JQuery. Internal researchers also have access via a direct JDBC/ODBC database.
connection that can be used to access data from QGIS, R software and the like. All elements of the Pladias platform are based entirely on open-source solutions. The described stack of services, except for PostgreSQL, runs in containers using the Docker abstraction layer on the Linux-based production server hosted by the Institute of Botany of the Czech Academy of Sciences. There are two regular Linux-based database servers running in streaming replication to ensure performance and stability.

Figure 1. doi
Screenshot of a taxon overview on the public portal pladias.cz.

Figure 2. doi
Screenshot of the online application with restricted access for researchers to work with the data at pladias.ibot.cas.cz.
More than 80 tables of PladiasDB are divided into five table schemas: atlas, geodata, measurements, pladias_functions and public. The table schemas are based on content unity or as a separate functional unit within the platform. We use materialised views for computationally intensive operations, in particular the data for Geoserver are preprocessed and recomputed once a day.

The full SQL schema and the ER diagram showing the relationships amongst described tables are published online in the Git repository at https://git.sorbus.ibot.cas.cz/pladias-public/database-structure (Novotný 2022).

Schema 1: atlas

Schema atlas is a core for storing occurrence data. Data are imported as Excel files from specific sources (atlas.projects), resulting in the creation of a batch (atlas.batch). Any errors found by automatic checkpoints are reported to the user in the form of annotated Excel files (atlas.excel). Data that pass validation checkpoints are stored as species occurrence records (atlas.records). The import only allows records with a point location and is linked to the quadrant of the basic fields of the Mapping of the Flora of Central
Europe (Ehrendorfer and Hamann 1965) quadrant. However, older records can be saved with location information that refers to the basic field (atlas.records_squares).

The remaining tables relate to record management and preparation of final versions of distribution maps for professional publications (e.g. Kaplan et al. 2015, Kaplan et al. 2021). All changes made since the dataset was imported are tracked in the database (atlas.records_history).

**Schema 2: geodata**

Spatial data, except for the location of species occurrence records, are stored immutably in the geodata schema. The main code lists are the basic fields ("squares") and quadrants (geodata.squares_full+quadrants_full) of the Mapping of the Flora of Central Europe, the phytogeographical division of the Czech Republic by Skalický (1988) (geodata.phytochorions) and the administrative division of the Czech Republic ( geodata.districts). Pladias is a purely national database that only allows the import of species occurrence records from the territory of the Czech Republic with a buffer of 50 m beyond the national border, which should compensate for most localisation errors. For the validation of records with coordinates falling slightly outside the national border, especially when determining the phytogeographical districts, we use an approximation (geodata.phytochorions_outside_cz), based on a buffer around the national borders divided by perpendicular lines as shown in Fig. 4.

**Figure 4.**

Phytogeographical districts of the Czech Republic and a buffer zone used for handling the records with coordinates falling slightly outside the national border. The districts at the national border are shown in colour.
The administrative division of the country is a hierarchical list, similar to other lists in PladiasDB, for example, the lists of taxa and syntaxa (see Schema 5 public). Four approaches are generally used to store the tree structure in relational databases (Celko 2012), each of which has certain advantages and disadvantages. The specific choice of the tree modelling approach is influenced by the context of use. In the case of Pladias, we have consistently used the Nested Set modelling approach shown in Fig. 5. Its advantages, which we appreciated during the operation, include in particular:

- It features high reading speed and is very good at handling aggregation within subtrees, so that all operations in the hierarchy of core lists can be performed on the fly;
- It is able to easily query the hierarchy when mining data at the level of handwritten SQL queries;
- It is also understandable for non-technical users.

The third point is very important. Exports of tables, such as taxon checklists, include the key columns (lft, rgt, depth, e.g. geodata.districts table) describing the taxon hierarchy so that users can work independently with the hierarchy in a simple spreadsheet.
Schema 3: measurements

Besides the occurrence data, the second essential part of the database is the module containing plant characteristics (traits, environmental associations and other information). These data are stored in the `measurements` schema. Each characteristic is represented in the database by an envelope called feature (`measurements.features`) with metadata, such as measurement units or accepted values. The import is done by the user in the form of an Excel file and, after validation, forms a separate set of characteristics (`measurements.traits`), i.e. metadata of a particular import. The actual data on plant characteristics are stored in tables (`measurements.data_*`), depending on the data type (`measurements.datatypes`).

To fill in missing values, we use the taxonomic tree (see Chytrý et al. 2021 for details) in several ways (`measurements.inheritances`). Four levels of precision are then available in the tables of plant characteristics (`entry_type` column in the `measurements.data_*` tables):

- original = data imported by users
- inherited = data from hierarchically superior taxa (e.g. species data transferred to a subspecies); this is only used if the conditions defined by the data type, inheritance type and taxon hierarchy constellation are met
- aggregated = similar to inherited, but originating from hierarchically subordinate taxa
- composite = a combination of all the above points

Data reproducibility is important for practical scientific use of stored data, but in shared databases, data on plant characteristics are constantly being corrected and added. Several times we used the low-level approach of creating a snapshot of the entire database and storing it as a reference state for a particular analysis, but we have reached the limits of this approach. The snapshot of the database contains complete data, including users' contacts, their activities and other data that would need to be deleted before providing them for peer-reviews. Not only the stored data, but also partial changes in the database structure evolve, complicating automated processes in creating the snapshots described above. For data on plant characteristics, we therefore created the table `trait_export_snapshots`, which stores the complete data in a 2D structure with an annotation to which analysis the snapshot belongs. The snapshots are saved as an Excel file and made available to researchers via the web application.

Schema 4: pladias_functions

The `pladias_functions` schema provides a repository of PL/SQL functions implemented to work with data, mainly for administration, technical management and data mining. Although the functions always work with a particular table, the context of their calls is highly variable. A clear separation of the functions into isolated schemas facilitates the overview of the implemented functionality.
At the moment, all functions are dedicated to processing the Nested Set hierarchy in taxa and partially in syntaxa. The only table in this schema, \textit{pladias\_functions.mptt\_taxons\_errors} stores error messages for these functions.

\textbf{Schema 5: public}

The default PostgreSQL schema is used to store the core lists of the entire platform – data tables for user accounts, checklists of taxa (\textit{public\_taxons}) and syntaxa (\textit{public\_syntaxons}) including their associated data structures. Both checklists use the Nested Set structure to store the hierarchy, as described above in the \textit{geodata} schema. The table names (\textit{public\_taxons/syntaxons}) intentionally use a grammatically incorrect form of the plural to follow the convention used for table names derived from the object in the application layer with the suffix "s". Therefore, we ignore irregular plural forms, such as \textit{taxa} or \textit{syntaxa}.

Taxon and syntaxon checklists are mandatory and no alternative concepts are allowed. This standardisation allows for efficient data management, which is particularly necessary because of the relational link to plant characteristics data at the database layer. To solve the issue of occasional changes in taxon names and delimitations, we adopted a synonym-derived solution. We arrange names representing different concepts in the table \textit{public\_synonyms}, which links names in the checklist with nomenclatural synonyms and names of taxa in different delimitations as adopted in important botanical monographs of the study area.

Some of the data stored in PladiasDB are original data, but most come from partially-aggregated sources (see Wild et al. 2019). These sources have very different licensing policies, which had to be accounted for by listing the licence for individual items, but also led us to create a security log of user activities. The \textit{public\_user\_activity\_log} table allows us to quantify each user's activities and capture potentially risky user behaviour.

\textbf{Web location (URIs)}

\textbf{Homepage:}  \url{https://pladias.cz/en/}

\textbf{Technical specification}

\textbf{Platform:}  PostgreSQL 12 + PostGIS 2.5

\textbf{Programming language:}  SQL

\textbf{Operational system:}  Linux

\textbf{Repository}

\textbf{Type:}  Git
Usage licence

Usage licence: Other

IP rights notes: The SQL structure of PladiasDB is licensed under MIT Licence

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Implementation

Implements specification

PladiasDB table description

Tables that model basic objects are named with the plural form of the entity name. Tables modelling M:N (many-to-many) relationships use the naming convention "table1_table2". The SourceSQL code, the ER diagram and additional information are published in the Git repository.

schema atlas (Table 1)
| Name              | Description                                                                 | Count of columns | Count of rows   |
|-------------------|-----------------------------------------------------------------------------|------------------|-----------------|
| authors           | persons who recorded plant occurrence in the field                          | 4                | 14,283          |
| batch             | metadata of the occurrence data import batch                                 | 6                | 18,503          |
| comments          | users’ comments on species occurrence records                               | 11               | 25,647          |
| csv_map_details   | additional information used for map rendering in the map publishing workflow  | 6                | 941             |
| excel             | Excel files containing original species occurrence records (validated/imported) | 9                | 17,452          |
| herbariums        | list of excerpted herbaria                                                   | 13               | 267             |
| institutions_users| administrator of a cooperating institution                                   | 2                | 0               |
| pdf_map           | PDF files containing distribution maps generated for use in printed publications | 6                | 2,651           |
| projects          | set of batches/species occurrence records sharing the same source of funding or licensing conditions | 6                | 15              |
| projects_users    | users allowed to import within a project                                     | 3                | 230             |
| record_originality_status | list of states for species occurrence records' originality status        | 4                | 4               |
| record_validation_status | list of states for species occurrence records' validity status           | 4                | 4               |
| records           | species occurrence records                                                   | 40               | 13,635,402      |
| records_authors   | M:N link table                                                               | 3                | 13,333,320      |
| records_herbariums| M:N link table                                                               | 2                | 506,159         |
| records_history   | log of any editing of species occurrence records after importing into the application | 9                | 5,051,082       |
| records_quadrants | M:N link table; Pladias allows old species occurrence records to be stored with inaccurate original locations by linking them to multiple adjacent quadrants. However, for ordinary users, the application layer only allows the import of point records, for which the linkage to the quadrant is calculated automatically | 2                | 13,543,850      |
| records_squares   | M:N link table; see above table public.records_quadrants                     | 2                | 38,604          |
| taxon_mapsettings | settings and progress in the map publishing workflow                          | 16               | 5,673           |
| Name | Description | Count of columns | Count of rows |
|------|-------------|------------------|---------------|
| taxon_mapsettings_publication | list of available states of progress in the map publication | 2 | 5 |
| taxon_mapsettings_revision | list of available states of progress in the map revision | 2 | 7 |
| taxons_users | M:N link table; the assigned user is a map administrator of the taxon, including all of its hierarchically subordinated taxa, an has the right to determine validation status and change the taxon identification | 3 | 1,413 |
| users_comments | users being not assigned as a map administrator can only comment on species occurrence records and propose changes for the revisers | 2 | 4,925 |

**schema geodata** (Table 2)

| Name | Description | Count of columns | Count of rows |
|------|-------------|------------------|---------------|
| districts | administrative division of the Czech Republic | 12 | 41,916 |
| districts_depth | list of available states for administrative district hierarchy level | 3 | 8 |
| phytochorions | phytogeographical districts of the Czech Republic | 7 | 215 |
| phytochorions_outside_cz | approximation of phytogeographical division outside the country borders | 4 | 89 |
| quadrants_full | grid of mapping quadrants | 10 | 40,000 |
| regions | polygons of regions for specific projects | 6 | 2 |
| squares_full | grid of basic mapping fields ("squares") | 4 | 10,000 |

**schema measurements** (Table 3)

| Name | Description | Count of columns | Count of rows |
|------|-------------|------------------|---------------|
| data_boolean | data on plant characteristics with Boolean data type | 4 | 59,957 |
| Name                          | Description                                                                 | Count of columns | Count of rows |
|-------------------------------|-----------------------------------------------------------------------------|-------------------|---------------|
| data_comment                  | pseudo-values for data on plant characteristics allowing comments on all data types | 4                 | 0             |
| data_enum                     | data on plant characteristics with nominal or ordinal data types            | 8                 | 10,296,633    |
| data_enum_syntaxons           | data on plant characteristics with specific data type that contains linking to the public.syntaxons table | 7                 | 37,688        |
| data_integer                  | data on plant characteristics with numeric data types                       | 6                 | 196,510       |
| data_interval_avg             | extension of the previous numeric data type used for storing a broader set of values | 9                 | 165,804       |
| data_month                    | data on plant characteristics with month data type                          | 6                 | 9,603         |
| data_occurrence_frequency     | data on species characteristics generated based on species occurrence records from the atlasmodule | 6                 | 27,792        |
| data_percentage               | data on plant characteristics with percentage data type                     | 4                 | 48,188        |
| data_real                     | data on plant characteristics with decimal number values                     | 4                 | 53,514        |
| data_real_multi               | data on plant characteristics with decimal number values and multiplicit values per taxon | 5                 | 287,866       |
| data_taxon_taxon_real         | data on plant characteristics with data type storing numeric (real) value for a set of two taxa | 5                 | 129,476       |
| data_unmeasurable             | pseudo-values for data on plant characteristics allowing to mark values that are not measurable in the given context (for example, flower colour for ferns) | 3                 | 2,820         |
| data_year                     | data on plant characteristics with year datatye                             | 7                 | 1,996         |
| datatypes                     | list of implemented data types for data on plant characteristics            | 13                | 14            |
| enumerates                    | metadata for nominal or ordinal lists of available values                   | 6                 | 104           |
| enumerates_values             | list of available values for nominal or ordinal data types                  | 9                 | 1,044         |
| features                      | metadata for plant characteristics                                          | 25                | 291           |
| inheritances                  | list of implemented inheritances, i.e. mechanisms for transferring values across a taxonomic tree | 4                 | 11            |
| sections                      | hierarchical structure of features                                          | 10                | 38            |
| trait_export_snapshots        | storage for backups of data on plant characteristics used for reproducibility of analysis, flattened into a 2D structure and Excel file format | 5                 | 11            |
| Name                                      | Description                                                                                           | Count of columns | Count of rows |
|-------------------------------------------|-------------------------------------------------------------------------------------------------------|------------------|---------------|
| trait_visibility_status                   | list of available states for availability of data on plant characteristics in various export/publishing services of the Pladias platform | 3                | 3             |
| traits                                   | metadata of specific series of data on plant characteristics                                          | 14               | 400           |
| units                                    | list of available units of measurement                                                               | 6                | 16            |

**schema pladias_functions** (Table 4)

Table 4.
PL/pgSQL functions in the `pladias_functions` schema. See Git repository for input/output parameters.

| Name of the function                       | Description                                                                                                                                 |
|--------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| descendant_taxon()                         | provides the entire subtree of the taxon, including itself                                                                                   |
| get_parents_if_singleton()                 | recursive function that returns a continuous series of parent taxa that are monotypic                                                       |
| get_taxon_cloud()                          | aggregates descendant_taxon() and get_parents_if_singleton() function results; used for rendering maps of taxa aggregating records with different level of identification accuracy |
| mptt_syntaxonsappendChild()                | add new syntaxion                                                                                                                          |
| mptt_taxonsappendChild()                   | add new taxon                                                                                                                              |
| mptt_taxons_delete_leaf()                  | delete taxon with no subordinate taxa                                                                                                       |
| mptt_taxons_delete_subtree()               | delete taxon and its subordinate taxa                                                                                                       |
| mptt_taxons_get_depth()                    | numeric approach to reach depth of tree                                                                                                     |
| mptt_taxons_get_error_code()               | help for error messaging when using PL/pgSQL functions                                                                                      |
| mptt_taxons_move_subtree_before()          | change the order of taxa belonging to a specific node. This function is used when changing the order of species listing inside one genus or other taxon; the parent (genus) remains the same, but the tree must be recalculated to change the order of species |
| mptt_taxons_move_subtree_real()            | move a taxon subtree within a specific node; this function allows rebuilding the taxon tree by moving a taxon and all its subtaxa to a new parent (hierarchically superior taxon) |
| mptt_taxons_repair_depth()                 | recalculation of taxon nodes’ depth                                                                                                         |
**Schema public** (Table 5)

| Name              | Description                                                                 | Count of columns | Count of rows |
|-------------------|-----------------------------------------------------------------------------|------------------|---------------|
| downloads         | static data provided in the web application                                | 11               | 3             |
| institutions      | institutions providing the plant occurrence data                          | 4                | 11            |
| licenses          | list of available licences for species occurrence records                  | 3                | 6             |
| publications      | essential recent overview publications on the Czech flora                  | 10               | 5             |
| syntaxon_ranks    | list of syntaxon hierarchy levels                                          | 5                | 5             |
| syntaxons         | core hierarchical list of syntaxa                                          | 33               | 674           |
| taxon_ranks       | list of taxon hierarchy levels                                            | 10               | 58            |
| taxons            | core hierarchical list of taxa                                             | 18               | 6,948         |
| taxons_synonyms   | taxon synonyms and invalidated taxon concept crosswalks mapped to the public.publications | 7                | 18,485        |
| user_activities   | list of logged activities                                                  | 2                | 21            |
| user_activity_log | logging users’ activity storage                                            | 7                | 4,170,445     |
| user_settings     | users' individual settings for web application                             | 3                | 7,541         |
| users             | web application users                                                      | 15               | 232           |

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