2 - 2021

BIOM

Revue scientifique pour la biodiversité du Massif central

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Roux & Thébaud / BIOM 2 (2021) : 51-61

BIOM/https://doi.org/10.52497/biom.v2i1.288 https://revues.bu.uca.fr/index.php/BIOM

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SurVegE-software for monitoring vegetation in permanent plots

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Submitted 22 february 2021
Accepted 3 april 2021
Published 1 june 2021

Abstract

UniVegE, Clermont Auvergne University, conducts research relating to the characterization of natural and anthropized habitats, from plant bio-indicators, for the purpose of management and conservation. Since 2005, this work has been supplemented by research and expertise relating to the diagnosis and monitoring of natural areas on permanent plots and along transects, on behalf of environmental partners: Regional nature parks, Espaces Naturels Sensibles of the departement 63, Clermont-Auvergne metropole... In this context 51 permanent plots have been set up in natural areas of the Massif central, territories of local authorities and/or protected areas. This experience made it possible to test new monitoring methods to concretely respond to managers' questions and lead to the development of the SurVegE software.

SurVegE (SURvey VEGetation Ecology) is an assistance software for the operator who manages natural areas. It allows, from floristic surveys carried out on bounded and georeferenced permanent plots, to characterize the floristic and ecological changes occurring between several years. The data analysis, integrated into the software and based on the values of benchmarks assigned to plant species, directly provides the comparative results quantified and illustrated, in the form of diagrams, figures and tables.

We will present here some features of the software, taking as an example concrete cases of studies carried out in the field. The sites selected correspond to different types of habitats and have been the subject of either initial reports or comparative diachronic analyses.

Keywords
Bio-indicator
Monitoring
Natural areas
Diachronis study
Management

Résumé

UniVegE, Université Clermont Auvergne, conduit des recherches qui ont trait à la caractérisation des habitats naturels et anthropisés, à partir des bio-indicateurs végétaux, dans une finalité de gestion et de conservation. Depuis 2005, ces travaux ont été complétés par des recherches et expertises portant sur le diagnostic et le suivi d'espaces naturels sur des parcelles permanentes et le long de transects, pour le compte de partenaires de l'environnement : Parcs naturels régionaux, Espaces Naturels Sensibles du département 63, Clermont-Auvergne métropole... Dans ce cadre 51 parcelles permanentes ont été mises en place dans des espaces naturels du Massif central, territoires de collectivités territoriales et/ou aires protégées. Cette expérience a permis de tester de nouvelles méthodes de suivi pour répondre concrètement aux questionnements des gestionnaires et déboucher sur l'élaboration du logiciel SurVegE.

SurVegE (SURveillance VÉGétation Écologie) est un logiciel d'assistance à l'opérateur gestionnaire d'espaces naturels. Il permet, à partir de relevés floristiques effectués sur des parcelles permanentes bornées et géoréférencées, de caractériser les changements floristiques et écologiques intervenus entre plusieurs années. L'analyse des données, intégrée dans le logiciel et basée sur des valeurs d'indices de référence affectés aux espèces végétales, fournit directement les résultats comparatifs chiffrés et illustrés, sous forme de diagrammes, figures et tableaux.

Nous allons présenter ici certaines fonctionnalités du logiciel en prenant comme exemple des cas concrets d'études menées sur le terrain. Les sites sélectionnés correspondent à différents types d'habitats et ont fait l'objet soit d'états initiaux, soit d'analyses diachroniques comparatives.

Mots-clés
Bio-indicateur
Suivi
Espaces naturels
Étude diachronique
Gestion

Introduction

In order to halt or limit the process of biodiversity erosion, many actors have mobilised to set up appropriate procedures. In Europe, this dynamic has led to an action plan for the protection of biological and landscape diversity, with the implementation of the habitats directive. The aim of this directive is to promote the protection and management of natural areas of heritage value through the Natura 2000 network. Every six years, the European Union assesses the application of the 1992 Habitats Directive (Directive 92/43/EEC) (DHFF), in the form of reports requested from member states on the conservation status of habitats and species (Bensettiti *et al.* 2009, 2015). For each local site involved in these European DHFF programmes, objective documents, including an assessment of current biodiversity, associated threats and guidelines for local management, are produced at regular intervals to improve the management of the natural areas concerned.

In France, many programmes or procedures concerning the preservation of biodiversity, habitats and natural areas are carried out by different actors: national parks, national nature reserves, regional nature reserves (regional councils), sensitive natural areas (departments), land acquisition and conservation management (conservatories of natural areas, regional nature parks, national botanical conservatories, etc.). These natural areas also require regular monitoring over time and in order to manage them as well as possible, methods and tools for monitoring and assessing the evolution of biodiversity have been put in place (Daget & Poissonet 2010).

In order to assess the dynamics of biodiversity and the quantitative and qualitative variations of plant species and their habitats, it is necessary to implement diachronic monitoring methods on permanent plots (Chytrý *et al.* 2009*). S*everal techniques are used to carry out relevés on these plots: floristic relevés, phytosociological relevés (Braun-Blanquet 1932, 1964), quadrats, etc. These can be coupled with the use of bioindicators: ecological indices (Ellenberg *et al.* 1992), forage value index (Daget & Poissonnet 1972), ecological groups (Duvigneaud 1946) and much work has been done in this direction for many years (Hawkes *et al.* 1997 ; Bartoli *et al.* 2000 ; Gégout *et al.* 2005 ; Hill & Carey 2009 ; Gaudin 2012).

It is with the aim of integrating and automating these widely shared methods that the SurVegE software was developed, in order to provide a diachronic and multifactorial diagnosis and a comparative analysis for vegetation monitoring using plant bio-indicators.

It is a tool that quickly provides a variety of phyto-ecological results from the relevés carried out, making it possible to provide assistance and advice to managers and conservators of natural or anthropised areas and environments. Its implementation requires field operators with botanical expertise. It was produced by UniVegE, from the University of Clermont Auvergne, and is the result of research conducted in the field since 2005 (Thébaud *et al.* 2012 ; Roux 2017). SurVegE is a tool that allows both phyto-ecological diagnosis and diachronic monitoring. It can be used only for the first purpose. However, its main advantage is that it combines the two.

Over the past 15 years, 69 permanent plots have been set up in 53 sites (Supplement 1) located in several departments of the Massif central (Puy-de-Dôme, Cantal, Haute-Loire, Loire and Nièvre). Several types of habitats are concerned: peat bogs, marshes, moors and submontane and montane grasslands, meadows, xeric slopes of plains, banks of ponds/lakes, alluvial vegetation and forests. These plots are located in natural areas, territories of local authorities (natural parks, departments) and/or protected areas (regional/national nature reserves, biotope decrees, etc.). These areas have been subjected to a phyto-ecological diagnosis as part of initial studies: characterisation of plant communities and habitats, ecological characterisation, identification of species with heritage status, uses and management. And since 2012, comparative diachronic analyses have been carried out on certain sites, detailed in various study reports. A methodological article presenting the software is currently being published (Roux & Thébaud, submitted).

In this article, we will look at different applications of the software through concrete cases. The data obtained during studies concerning several sites and habitats are analysed and the procedure for obtaining the diagnosis provided to site managers is explained.

Methodology

General structure of the software

The database currently integrated into the software is formed from the taxonomic repository TaxRef v.12 (Gargominy *et al.* 2018) supplemented by index values of Ellenberg (1992) and, for the uninformed taxa, the ecological indices of Julve (2017) sare adopted, with some exceptions that are then documented by UniVegE. Some bryophytes, in particular peat bogs, are documented by index values calculated by UniVegE from Dierssen (2001). For the taxa of agropastoral environments, the specific indices of forage values come from Daget & Poisonnet (2010). Not all taxa have index values but the software allows to complete them.

SurVegE works on Windows (from Windows 7) and Linux, locally. The software exports the illustrations in bitmap and vectorized formats in order to be able to rework them, if necessary, on specialized software. And the tables are exported in csv format.

Floristic relevés are entered directly into the software, but it is possible to import them from Turboveg (SDF formated database) (Hennekens & Schaminée 2001).

Detailed explanations of the software are provided in a user guide.

Setting up permanent plot

The method consists of setting up in the field a PSET (temporal socio-ecological profile; Fig. 1), a permanent sequence made up of several sections, corresponding to a given area, bounded and georeferenced, in which vegetation relevés are carried out over

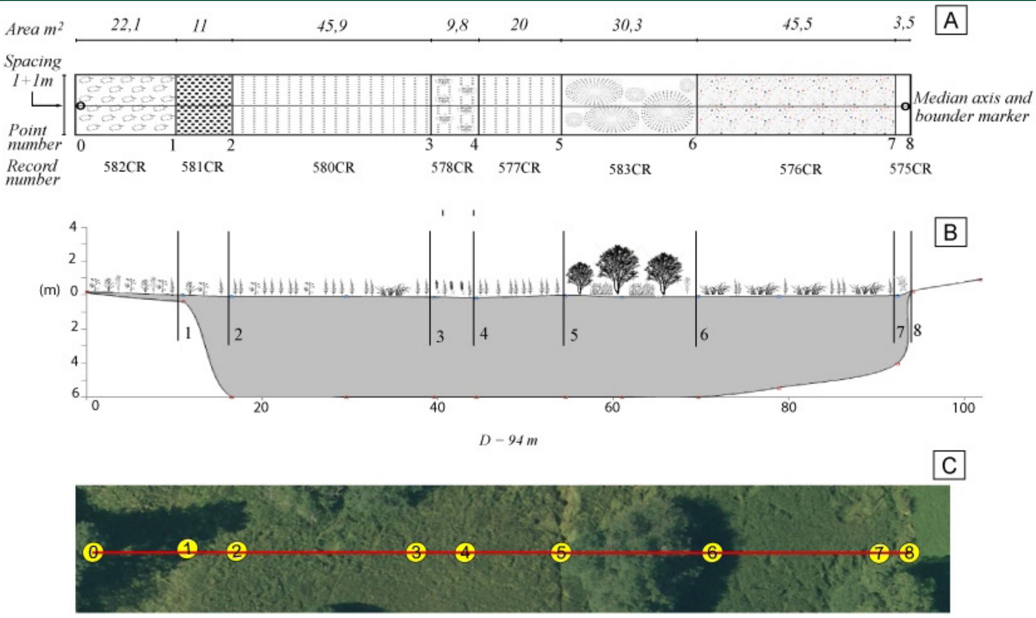

Figure 1 - A): toposequence of studied vegetation seen from above; with, from top to bottom: the recorded areas, the points delimiting the different sections; the corresponding relevés numbers. B): toposequence of the same vegetation in sectional profile; the topographic profile, the depth of the peat (the latter only in this particular case) with scales of height and distance. C): visualization of the sequence on the aerial photo.

time. In the case of carrying out topographic surveys along the PSET, a device of the tacheometer type is used. The height of each point separating the vegetation sections and their horizontal distance from the zero point where the tacheometer will be placed is thus measured. Additional measurements can be taken (peat depth for example ...) that SurVegE can illustrate.

In the event that a topographic profile is not produced, it will nevertheless be necessary to measure the distance on the ground, from the zero point, between the different points of separation of the vegetation sections.

Performing a PSET is the recommended method for optimal use of SurVegE software. But the software is also suitable for monitoring simple vegetation relevés on isolated plots or specific plant species.

Whether the plots are in the form of line transects or non-contiguous relevés, they must be georeferenced by GPS and bounded by a metal terminal (or magnet) driven into the ground. It is imperative to be able, several years later, to find these points very exactly in order to carry out new relevés in the same sections.

Relevés of vegetation

The software is compatible with several types of vegetation relevés, carried out along the PSET or on an isolated permanent plot: phytosociological relevés (Braun-Blanquet); relevés on quadrat points; phyto-ecological relevés of bio-indicators; individual species relevés.

For each relevé, in addition to the taxonomic identification of all species present, the % of total vegetation cover, of each vegetation layer, litter, bare soil and outcropping boulders will be recorded; as well as stationary data (altitude, aspect, slope, etc).

To provide information on the abundance of each species, SurVegE offers several options: we can note the exact% abundance, or assign an abundance coefficient according to Braun-Blanquet which corresponds to an abundance class whose value is estimated in relation to the total surface area of the relevés, varying from r to 5. Here again, the software offers several options concerning the abundance classes: "Braun-Blanquet old", "Braun-Blanquet new" and "Braun-Blanquet extend"; each determining an increasingly fine degree of precision of the abundance classes (Tab. 1). During the survey, the dominance can be noted, but it will not be entered in the software, as it is not taken into account in the calculations

Tableau 1 - Choice of abundance classes proposed in SurVegE.

Braun-Blanquet old Classe	%	Moy	Braun-Blanquet new Classe	%	Moy	Braun-Blanquet extend Classe	%	Moy
5	]75-100]	87.5	5	]75-100]	87.5	5b	]87.5-100]	93.75
4	]50-75]	62.5	4	]50-75]	62.5	5a	]75-87.5]	81.25
3	]25-50]	37.5	3	]25-50]	37.5	4b	]62.5-75]	68.75
2	]5-25]	15	2b	]15-25]	20	4a	]50-62.5]	56.25
1	]1-5]	3	2a	]5-15]	10	3b	]37.5-50]	43.75
+	0.5	0.5	1	]1-5]	3	3a	]25-37.5]	31.25
r	0.1	0.1	+	0.5	0.5	2b	]15-25]	20
			r	0.1	0.1	2a	]5-15]	10
						1	]1-5]	3
						+	0.5	0.5
						r	0.1	0.1

The relevés carried out according to the Braun-Blanquet method, that is to say in abundance classes, are less precise than the abundance readings in absolute value. But the former require only a third to a fifth of the field time required for the latter and provide sufficiently precise baseline data to allow the assessment of the impact on the environment (Wikum & Shanholtzer 1978). They also allow a direct identification of the plant community concerned according to the European synsystem (Mucina *et* *al.* 2016) or according to the prodrome of the vegetations of France (PVF1/Bardat *et al.* 2004 and PVF2/Société Française de Phytosociologie). As well as a characterization of the habitat and its affiliation to community directives or international conventions using for example HABREF which groups together the reference typologies of each territory (Clair *et al.* 2019).

Use of plant bio-indicators

Plant bioindicators make it possible, from floristic data collected in the field, to provide ecological indications allowing the diagnosis of the initial state and evolution of the site studied. Each taxon has an index value and for a relevé, the software calculates the average of the index values (light, humidity, temperature, pH, nutrients, salinity and continentality) weighted by the abundance of the taxa. This is why it is very important to be particularly rigorous when carrying out a relevé by abundance classes, otherwise you will obtain biased or even inconsistent results.

Data entry in SurVegE

For the software to work, all you have to do is enter the vegetation relevés carried out in the field. First of all, the year of the survey and the first section of the sequence must be entered, then the method used to calculate the abundance of taxa must be chosen. Then fill in the head data of the vegetation relevé: relevé number, station data, cover, spacing, surface, geology, etc. The relevé can then be entered, specifying the stratum and abundance for each taxon. For each taxon entered, the corresponding ecological indices and specific indices of forage value can be viewed and completed if necessary.

In the case of a PSET, the topography of the transect carried out in the field can also be entered. The altitude of the first point of the sequence, the locality, the municipality, the general orientation of the sequence (drop-down list) and the coordinate system used (drop-down list) are entered. The relative height in metres given for each point is that of the zero point (position of the tacheometer) subtracted (downward slope) or increased (upward slope) by the topographical difference observed thanks measuring staff; the cumulative distance from point 0 is noted in metres to the last point, thus obtaining the total length of the sequence; these data are completed by the X and Y coordinates of each section/relevé and possibly by the measured depth (soil, peat, water) in meters (Fig. 2).

It is not necessary to make topographical measurements for the various applications of the software, but if one chooses to set up a transect, i.e. a continuous sequence of several relevés, it is nevertheless necessary to measure the distance on the ground, in relation to the zero point, between the different points separating the vegetation sections, in order to obtain the relevé area.

Figure 2 – Setting up a PSET in the field. From left to right: laser level to measure the distance between each section; bar code sight to measure height and graduated metal pole to measure the depth of peat; rope marking the toposequence on the ground.

Description of software applications based on results obtained at monitoring sites

SurVegE can be used for all types of environments, so we have chosen various sites with different habitats as examples to present the functionalities:

- An acidic sphagnum peat bog, the Prénarde peat bog (Saint-Jean-Soleymieux, 42; ZNIEFF I n° 820032401), is being monitored in the form of a toposequence of 172 m. This was set up in 2008 by UniVegE, in order to analyse the free evolution of the vegetation after the abandonment of grazing; since the same period, it has been studied from a hydro-ecological and paleo-environmental point of view by ISTHME laboratory of the University of Saint-Etienne.
- A submontane marsh, the Fontfreyde marsh (Saint-Genès-Champanelle, 63 ; UNESCO site FR7100006), located in the Volcans d'Auvergne Regional Nature Park (PNRVA), has been identified as a priority wetland on the territory of Clermont Auvergne Métropole, and the latter has entrusted a phyto-ecological and paleo-environmental study since 2012 to the universities of Clermont-Ferrand (UniVegE) and Saint-Etienne (ISTHME); the permanent monitoring corresponds to a toposequence of 102 m.
- A pastoral moor on the subalpine edge of the Monthiallier mountain (Job, 63; ENS, NATURA 2000 FR8301030; ZNIEFF I n°830005443; classified site of the «Haut-Forez central»), located in the Livradois Forez Regional Nature Park. The Puy-de-Dôme Departmental Council has designated the site as a Sensitive Natural Area and in 2012 entrusted UniVegE with a monitoring project to observe the dynamics of the vegetation there. This corresponds to a toposequence of 45 m.
- A submontane pastoral grassland on the puy de la Combegrasse (Aydat, 63; UNESCO site FR7100006; classified site of the «chaîne des Puys»), located in the Volcans d'Auvergne Regional Nature Park, in the chaîne des Puys. A study was commissioned to UniVegE by the PNRVA, in 2015, in order to monitor the evolution of these estives following a clearing conducted by the Syndicat Mixte de Gestion Forestière d'Aydat.

This monitoring is carried out in the form of a toposequence of 95 m.

- A Limagne xerothermic limestone hillside of high botanical interest, puy Long (Clermont-Ferrand, 63; ZNIEFF I n°830005667) located on the territory of Clermont Auvergne Métropole. As part of the biodiversity plan, the latter has entrusted UniVegE with monitoring the vegetation since 2012; it corresponds to a toposequence of 56 m.
- A sector of the banks of the Allier River, at the place called «Les Boires» (Pont-du-Château, 63; NATURA 2000 FR8301038, ZNIEFF I n° 830000178). The municipality has entrusted UniVegE with monitoring since 2013 in order to observe the free evolution of the minor bed. This corresponds to a toposequence of 190 m.

These sites present a variable gradient of anthropic pressure. Some have been in free evolution for more than 50 years (Prénarde, Fontfreyde, les Boires); others are subject to extensive grazing (Combegrasse, Monthiallier); the last site, due to its proximity to the Clermont-Ferrand metropolis, is subject to greater impacts: regular use by walkers, motorised vehicles, immediate proximity of a former landfill site, a waste disposal centre and a scrapyard.

Applications related to phyto-ecological analysis

Automatic production of a floristic distribution diagram

SurVegE reaches its optimum use in the case of a PSET-type profile; the software then automatically provides a complete diagram of the vegetation transect (Fig. 3), with the taxa in the rows and the various relevés corresponding to the sections of the toposequence in the columns, respecting the proportions of the distances. It can thus be used to diagnose the initial state and indirectly highlight, through the taxa, ecological gradients, dynamic successions or to report on contacts and transitions between communities. SurVegE can also be used to automatically modify the order of the taxa that appear in the diagram according to their ecological index value or by manually classifying them, by moving the corresponding lines, in order to produce a diagonal table of taxa.

The diagram in figure 3, produced in the Prénarde peat bog, shows a decreasing moisture gradient from 2 to 9 after classification of the taxa. It also shows two functional compartments and a dynamic succession. A first compartment upstream (from 6 to 9), on organo-mineral soils, under the

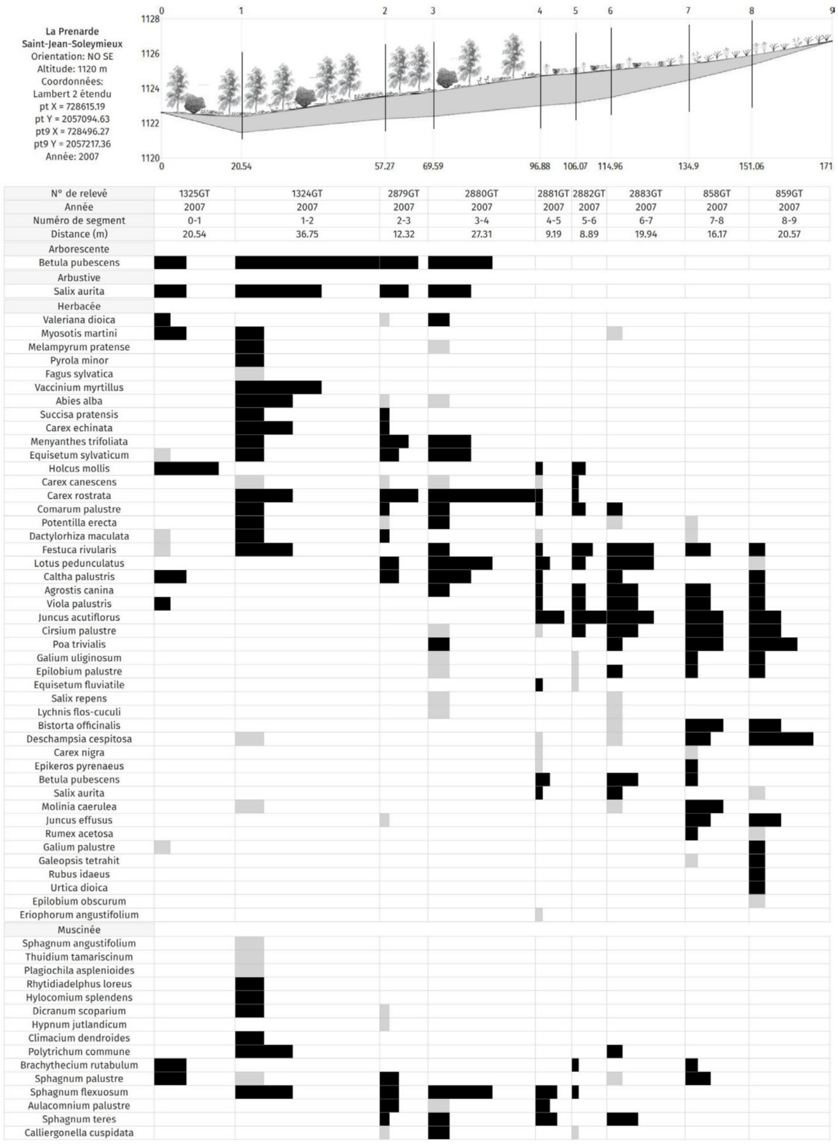

Figure 3 – Example of a PSET initial state diagram carried out in 2007 in the Prénarde peat bog (Saint-Jean-Soleymieux, 42). Topographical profile and peat depth profile. From 0 to 9: different sections of the profile where the vegetation relevés are carried out, each located between 2 topographic points. The species are classified in such a way as to obtain an ecological gradient, in this case a moisture gradient decreasing from 2 to 9. The illustrations of the profile are not incorporated into the software but added after exporting in .jpg or .svg format.

influence of the slope, mesotrophic and dried out in summer, is formed of rushes with *Juncus acutiflorus* Ehrh. ex Hoffm. and meadows with *Deschampsia cespitosa* (L.) P.Beauv. (habitat of community interest EU 6410), mesohygrophilous, and a second compartment (from 1 to 6), more regularly flooded, turfy, rich in sphagnum mosses and hydrophilous taxa, is occupied by low marsh type communities. The latter is the seat of a secondary dynamic succession that leads from the pioneer stages (3-4) to a more mature stage of the bog (1-2). It will lead to a head of the fir-tree turfic forest series (*Betulo pubescentis-Abietetum albae* Lemée 1995, habitat of EU Community interest 91D0), which has not yet been fully realised in this profile; a certain drying out in 1-2 can already be observed, which will be accentuated when the firs grow

Automatic production of quantitative comparative results from Index values

- The use of ecological indices in SurVegE allows two main types of information to be obtained:
- Phyto-ecological comparison, for the same year, between each section of a toposequence or between several non-contiguous relevés;
- Diachronic comparison based on observed vegetation changes.

SurVegE thus makes it possible to obtain directly comparative results for each of the indices in the form of different illustrations and associated tables of values. We briefly develop three examples below to illustrate some of the types of results produced by the software.

Example of diachronic analysis on the puy Long site. This Limagne peperitic hillside is mainly occupied by communities of xerothermic oligotrophic grasslands, more or less open (habitats of community interest EU 6110 and 6210). The diachronic analysis (2012-2019) showed an increase in the occurrence and abundance of nitrophilous plants and thus in the nutrient index (N) in most of the transect (Fig. 4). Only sections 4-5 and 5-6, located on the southern slope, have lower index values than in 2012, a consequence of regular soil erosion at this steep location. This increase in nutrient content along the profile may be a consequence of probable deposition of nitrogenous organic compounds from the former landfill adjacent to the site.

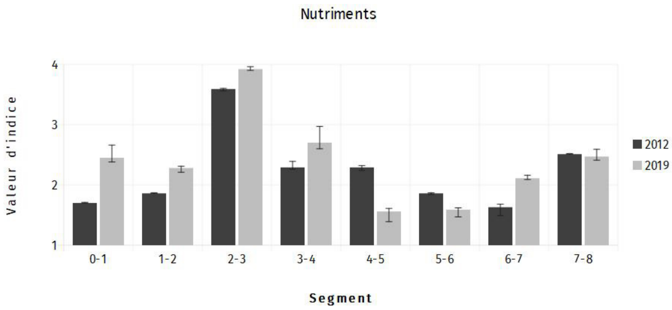

Figure 4 - Figure directly produced by the software, corresponding to histograms with error bars. They present the variation of the means of the nutrient index values, between 2012 and 2019, for each of the sections of a toposequence carried out on the puy Long site (Clermont-Ferrand, 63). The error bar is obtained by calculating the Ellenberg indicator values of the survey with the % of maximum and minimum abundance of the abundance class

Example of a diachronic analysis of the Fontfreyde marsh. Figure 5 shows the variation in temperature index values (T) between 2012 and 2019 in this marsh.

It can be seen in this example that the increase is general in all sections. Section 3-4, in the centre of the marsh, is the most impacted, and the shaded and buffered willow grove (5-6) shows the least change. By studying the floristic composition of the sections in more detail (see paragraph: Variations by taxon) we noted a disappearance of montane mesocryophilous species and an increase in submontane to hilly mesothermophilous species, elements that support and explain the increase in the T index observed.

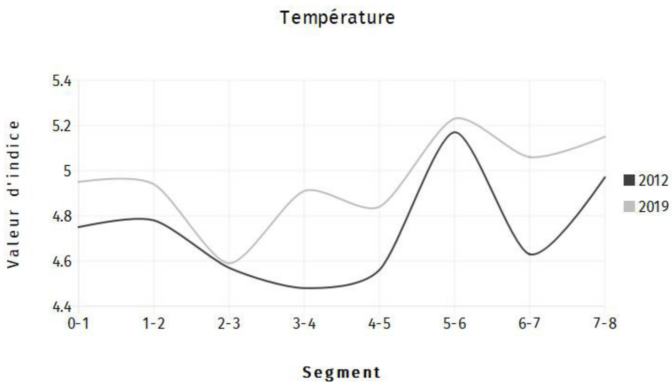

Figure 5 – Figure directly produced by the software corresponding to curves showing the variation of the average values of the temperature index, between 2012 and 2019, for each of the sections of a toposequence carried out on the Fontfreyde marsh. Here the y-axis is dynamic, but it can be exported as a global scale, i.e. it displays all the indices present for an ecological variable, so the visual difference between the curves becomes less pronounced.

Example of a phyto-ecological comparison of heathlands in the Massif central. In this example, the software allows several variables to be compared on the same illustration and to give directly, in the form of radar figures, the ecological spectrum of four relevés carried out in various stationary situations, far from each other, in order to highlight their differences. Figure 6 shows the profiles carried out in these low acidiphilous moors of the Massif central (habitats of EU interest 4030 and 4060). The first three were carried out in the subalpine belt, at different exposures (two in the monts Dore and one in the monts du Cantal) and the fourth in the Limousin at the submontane belt.

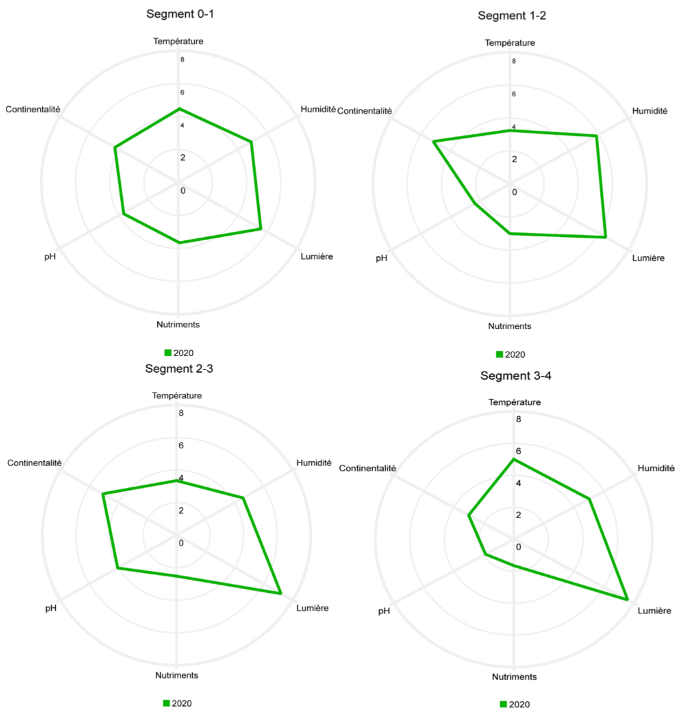

Figure 6 – Radars representing the values of ecological indices (temperature, humidity, light, nutrient content, soil reaction and continentality) of 4 heaths located in the Massif central: 0-1: subalpine chionophilous heath of the monts Dore; 1-2: subalpine cryosciophilous heath on the ubac of the monts Dore; 2-3: subalpine helioxerophilous heath on the summit of the monts du Cantal; 4-5: lowland, humid, Atlantic heath of the Limousin.

In addition to these results and illustrations, the SurVegE software provides a table of the raw values of the ecological indices of light, humidity, temperature, pH, nutrients, salinity and continentality, as well as the values of the indices of specific richness, Shannon and regularity in a table that can be exported from the software (Tab. 2).

Production of results in the form of index classes

This feature of SurVegE makes it possible to group the taxa of each section according to their index class (ecological affinity), for each ecological parameter. It helps to understand and to interpret the variations in Ellenberg index values observed in parallel at a given site.

The example given here is the monitoring of the Fontfreyde marsh toposequence. The software analyses the floristic composition of each section, classifying the species according to their ecological affinity for the «humidity» parameter. It directly provides the distribution of each index class, from the driest to the wettest, along the toposequence. Figure 7 shows the results, in the form of curves, for species in index class 8 (mesohygrophilous to hygrophilous) and for index class 10 (heliophytes).

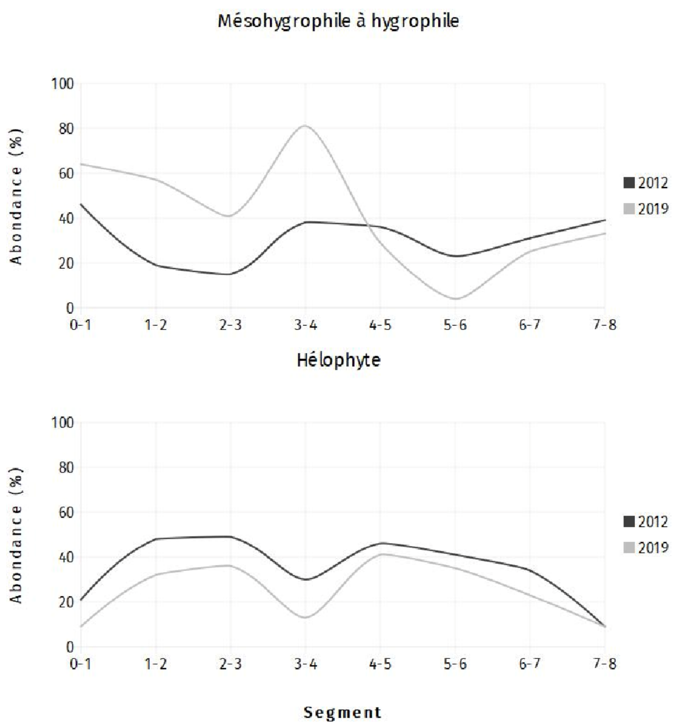

Figure 7 – Sum of the abundances, in percentage, of the taxa grouped by Ellenberg index class for the variable «humidity» and by section. Here we compare the percentage abundance of mesohygrophilous to hygrophilous taxa (class 8) and heliophytes (class 10) between 2012 and 2019 at Fontfreyde marsh.

Tableau 2 – Example of a table, directly produced by SurVegE, giving the results of the calculations in the form of the values of the ecological indices as well as those of the Shannon index, species richness and evenness, for each section/relevé.

N° de relevé	Année	Segment	Shannon-Wiener	Richesse	Régularité	Lumière	Température	Continentalité	Humidité	pH	Nutriments
582CR	2019	0-1	1.64	17	0.58	7.04	4.95	4.94	7.97	5.21	4.92
581CR	2019	1-2	1.7	12	0.69	7.2	4.94	4.67	8.68	5.43	5.34
580CR	2019	2-3	1.87	20	0.62	7.6	4.59	4.5	8.83	4.66	4.14
578CR	2019	3-4	1.33	11	0.55	7.65	4.91	3.88	8.32	4.13	3.47
577CR	2019	4-5	1.88	16	0.68	7.63	4.84	4.57	9.05	5.4	4.81
576CR	2019	5-6	0.94	13	0.37	7.36	5.23	3.77	7.52	4.97	4.91
575CR	2019	6-7	1.69	14	0.64	7.07	5.06	4.73	8.96	6.28	5.85
579CR	2019	7-8	2.1	16	0.76	6.43	5.15	3.81	7.65	5.55	5.78

In 7 years, a general decrease in the values of the «humidity» index has been observed in the Fontfreyde marsh. Figure 6 shows an increase in the percentage of class 8 species (mesohygrophilous to hygrophilous, irregularly flooded) in the first 5 sections of the sequence in 2019 and a parallel decrease in class 10 species (helophytes, permanently flooded). From these results, it could be deduced that the general decrease in moisture content observed was related to a reduction in the flooding period of the marsh. This leads to a change in vegetation composition with the establishment of a megaphorbia with *Filipendula ulmaria* (L.) Maxim, with *Persicaria lapathifolia* (L.) Delarbre (EU habitat 6430) at the expense of quaking bog with *Carex nigra* (L.) Reichard and *Equisetum fluviatile* (EU habitat 7140), taxa whose individual variations are monitored elsewhere (§ Variations per taxon).

Production of results by strata and vegetation cover

This application displays the percentage abundance of vegetation cover for each of the tree, shrub, herb and musk strata, for bare soil, litter and mineral outcrops (rocks...). By comparing several years, it is possible to observe the structural changes in vegetation and surface cover.

We give here the example of a toposequence carried out in an alluvial environment, on the banks of the Allier at a place called «Les Boires» (Pont-du-Château, 63). It is composed of an old pond that has recently been filled in, forest hemlines, an alluvial forest and exposed shorelines. The monitoring was carried out over a time step of 6 years (2013-2019); Figure 8 shows the structural changes observed, in the form of histograms displaying the cover values in % for each section of the toposequence in 2013 and 2019.

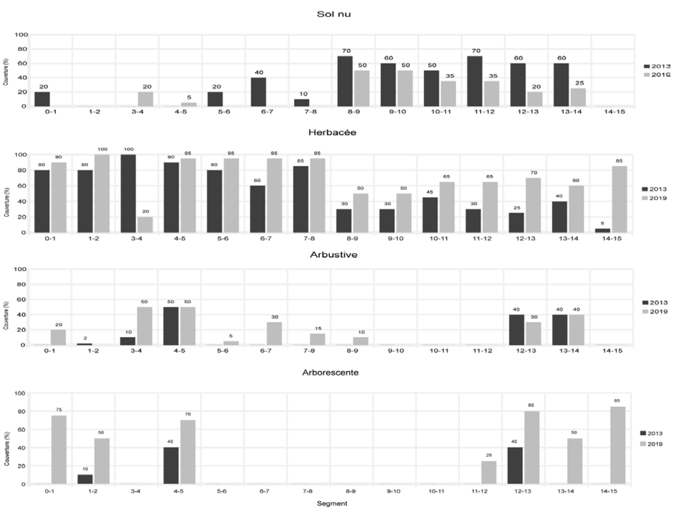

Figure 8 – Abundance of cover, in percentage, for the tree, shrub, herb and bare ground strata, for the years 2013 (black) and 2019 (grey), in an alluvial site (Les Boires, Pont-du-Château). Above each column the percentage of the stratum is displayed.

The tree stratum is present at both ends of the transect (drinking water sector, then alluvial forest and Allier riverbank sector). At the level of the riparian vegetation (12-13, 13-14, 14-15), we can note the existence of a tree stratum that was not present in 2013 (due to the establishment of a pioneer poplar grove); section 4-5 shows an increase in tree cover (reflecting the maturation of an ash and elm grove forest already in place in 2012; EU 91F0 community interest habitat). The development of the shrub layer in 2019 is mainly observed in sections 6-7, 7-8, 8-9 (banks colonised by young shoots of Populus nigra L.). It reflects a dynamic towards the willow and poplar forest (removal of the water table following the displacement of the Allier River). There is also a clear increase in the cover of the herbaceous layer on the shoreline between 2013 and 2019 (especially sections 8-9 to 14-15); this is at the expense of the bare soil.

It can also be observed that in the dry old pond (section 0-1) the vegetation dynamics is very fast since in the space of 7 years trees and shrubs have developed to the detriment of the bare soil.

The information on the cover provided by the software therefore allows precise monitoring of the vegetation dynamics.

Provision of a qualitative taxonomic balance between different years

The software automatically provides a qualitative taxonomic balance between several years, within a single relevé or within each section of a sequence. This allows a better understanding of the changes in Ellenberg index values between these years.

To illustrate this functionality, the Monthiallier site is given here as an example. The site consists of subalpine heaths to the upper forest edge (habitat of community interest EU 4030) and a «subalpine» beech forest (habitat of community interest EU 9140). Table 3 shows the species that were present only in 2012 and only in 2019.

Tableau 3 – List of taxa that have 'appeared' or 'disappeared' in the Monthiallier toposequence between 2012 and 2019.

2012
Betula pendula Roth
Bistorta officinalis Delarbre
Campanula rotundifolia L.
Dianthus seguieri Vill. subsp. *pseudocollinus* (P.Fourn.) Jauzein
Dryopteris x deweveri (J.T.Jansen) J.T.Jansen & Wacht.
Hieracium sp. L.
Knautia basaltica Chass. & Szabó var. *foreziensis* (Chass. & Szabó) Breton-Sintès
Lactuca plumieri (L.) Gren. & Godr.
Luzula multiflora (Thuill.) Arcang.
Narcissus pseudonarcissus (L.) Rouy
Oxalis acetosella L.
Ranunculus platanifolius L.
Rubus idaeus L.
Sanguisorba officinalis L.
Senecio cacaliaster Lam.
Serratula tinctoria L. subsp. *monticola (Boreau) Berher*
Solidago virgaurea L.
Thesium alpinum L.
Veratrum album L.

2019
Carex umbrosa Host
Hypochaeris maculata L.
Sorbus aria (L.) Crantz

There was a very significant overall 'disappearance' of taxa in 2019 compared to 2012 (Tab. 3). In fact, 18 taxa, present in 2012, were not seen again in 2019. Conversely, only 3 taxa, seen in 2019, had not been seen in 2012. Among the missing taxa are many species with an hygrophilic charactere, such as *Bistorta officinalis*, *Narcissus pseudonarcissus*, *Sanguisorba officinalis*, *Luzula multiflora* and mesotrophic taxa of the phytosociological class *Mulgedio-Aconitetea* Hadač & Klika 1944, a class of tall subalpine herbs that thrive on deep or moist, relatively nutrient-rich soils, such as *Lactuca plumieri*, *Ranunculus platanifolius*, *Senecio cacaliaster* and *Veratrum album*. A possible deduction from these observations is that there is a natural reduction of the snowdrift (decrease in the duration and thickness of the mantle) causing the decrease or disappearance of these taxa. The software can thus be used to highlight changes in vegetation due to more general climatic factors

Variations by taxon

Figure 9 shows, for example, the evolution of the abundance of the *Ligularia siberica* (L.) Cass., in the permanent monitoring toposequence set up in the Fontfreyde marsh, for the years 2012 and 2019. This species is a glacial relict in decline, it is listed in the «Habitats-Fauna-Flora» Directive: appendices II and IV; the Bern Convention: appendix I; it is a protected species at the national level in France (appendix I) and is listed by the IUCN for France as vulnerable.

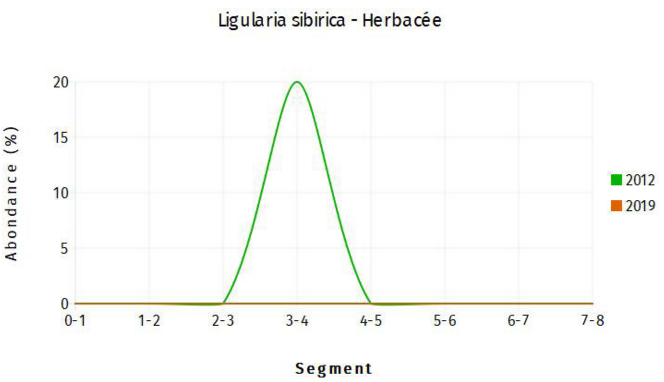

Figure 9 – Percentage abundance of *Ligularia siberica* (L.) Cass. along the toposequence. It can be seen that this taxon was only present in section 3-4 in 2012 (20%) and has completely disappeared from the sequence in 2019.

Observations have shown that it will disappear in 2019. The reduction of the flooding period of the marsh (paragraph index class), has a strong negative impact on the development and maintenance of the population. This factor coupled with the increase in temperature index values (paragraph index values), the disappearance of other montane species (not presented here), and an increase in nutrient index values (not presented here) all leading to competition with tall meadow herbs (Heinken-Šmídová & Münzbergová 2012 ; Cîslariu *et al.* 2018), suggests that the Ligularia station is in peril in Fontfreyde marsh.

On the basis of this observation, it was decided to carry out a precise count of Ligularia plants in the whole of the Fontfreyde marsh in order to be able to monitor, as accurately as possible, the evolution of the population in the years to come. A new monitoring of the toposequence is planned for 2024 in order to see if the trends of the drying up of the marsh and the increase in temperature are confirmed.

Applications related to agro-pastoral analysis

An agro-ecological module completes the SurVegE software. For each of the sections of the profile (or isolated relevés) it allows the calculation of the pastoral value (VP') in relation to the % of the herbaceous stratum, from the values of a specific index of forage quality (IS) attributed to each taxon and the specific frequency of these (FS). The adapted stocking rate per hectare for a given period can thus be deduced (Loiseau 1989) and thus provide a basic reference for herd management. The specific index of forage quality (Daget & Poissonet 1972, 2010) varies from 0 to 5, with 0: non-forage species (*Thesium humifusum* DC.) and 5: very good forage (*Dactylis glomerata* L.). SurVegE provides, in this module, the pastoral values, a histogram classifying the taxa by forage affinity and it gives the possibility to follow the specific frequency of a given taxon over time.

Such a study was carried out on the puy de la Combegrasse. This puy was covered by a pine forest which was cleared in order to put the grassland back into summer pasture. Since 2014, a flock of sheep has been grazing these grasslands. The permanent monitoring plot was set up in 2015 and the monitoring was carried out in 2020.

The main result is the appearance of «good forage» species (IS=4 and 5, *Dactylis glomerata* L., *Lotus corniculatus* L., *Poa pratensis* L., etc.) and the increase in the percentage values of «medium forage» in 2020 compared to 2015 (IS= 1 to 3) (Fig. 10A). It can also be seen that the percentages of bare ground and litter have decreased significantly between 2015 and 2020. Confirming these trends, the pastoral value increases significantly in 2020 (Fig. 10B). From the point of view of the pastoral value of this rangeland, an improvement in quality can be observed, which leads to the conclusion that the current pastoral practices have a general beneficial effect.

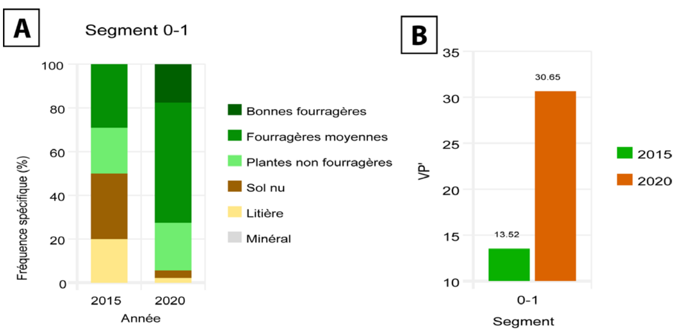

Figure 10 – A) Comparative histograms between the years 2015 and 2020 of the specific contributions of each species group and bare ground/litter; B) histogram representing the pastoral values determined for each year.

This study will be continued in the years to come, with particular attention paid to signs of overgrazing with the appearance of erosion and thus an increase in the percentage of bare ground/litter or, on the contrary, undergrazing with the appearance of colonising woody plants.

Conclusion

SurVegE does not aim to define new methods of vegetation analysis, but it does have the advantage of integrating widely used tools into a single application. It allows the user to obtain automatically, from the relevés carried out in the field, the results relating to the diagnosis and the changes in vegetation, in the form of tables and illustrations. The user can thus easily exploit the results related to ecological variables and manipulate a large number of parameters, while avoiding tedious calculations, thus saving time when exploiting the data.

The use of plant bio-indicators in the diachronic comparative analysis allows to observe changes in the vegetation. With this approach even small variations are observable by a few years (Combegrasse 5 years; Les Boires 6 years; Fonfreyde, Monthiallier and puy Long 7 years). In many of the examples cited in this article, the sections of the permanent toposequences were always attached to the same habitat (or the same plant association) at the time of monitoring, whereas changes in the latter were observed. This approach therefore makes it possible to rapidly implement fine-tuned management adapted to each site.

In order to be able to observe variations in vegetation, linked to climatic changes or dynamics, it is necessary to follow the plots for several decades. It is therefore essential to mark them out and geolocate them rigorously, as diachronic comparison will only provide usable results if the exact same sections are followed over time. If old monitoring plots have been marked and geolocated and the abundance of taxa present has been recorded, it is quite possible to enter the information into SurVegE in order to continue the previous monitoring. The analysis of changes in vegetation can then be carried out from the date on which these permanent plots were set up, thus ensuring that the data collected is not lost and that the monitoring continues with the support of the software.

It is known that, in general, the results of a diachronic comparison between vegetation observed on the same plot can depend greatly on the observer. It is therefore recommended that great care be taken when carrying out the surveys and assigning the abundance class that is closest to reality; the software user guide also provides precautions to be taken in this case.

The analysis of vegetation changes is a complex process and must take many factors into account; in no case does SurVegE give an interpretation. It should not be used in a simplistic way by limiting the reflection to the observation of a single parameter and for too short a period. Such an approach could be negative and therefore lead to inappropriate management.

As SurVegE is an evolving software, it can be completed and improved by new modules in the future. To obtain the software, please visit the UniVegE website (https://herbiers.uca.fr/version-francaise/survege) to obtain the terms and conditions for purchasing a licence key with which the user guide will be provided. A training course on how to set up permanent plots in the field and use the software in the classroom will also be offered.

Acknowledgements

SurVegE has been developed and tested on several permanent plots of various local authorities: the Conseil départemental du Puy-de-Dôme, Clermont Auvergne Métropole and the Parc des Volcans d'Auvergne, which we would like to thank here.

The development of the software was financially supported by the Ministry of Ecological Transition and Solidarity, the environmental research federation of the University of Clermont Auvergne and the French government's IDEX-ISITE 16-IDEX-0001 (CAP 20-25) initiative awarded to the Clermont-Ferrand university cluster.

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