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ITV-net: leveraging intraspecific trait variability to bridge vegetation science and trait-based research in Italy*

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Abstract

Vegetation science is a branch of community ecology that relies on species identities and abundance to classify vegetation in coherent units and to explore species coexistence and turnover dynamics. The advent of trait-based ecology has expanded vegetation science, providing a framework that allows for a better understanding of plant strategies and the functional structure of communities. These complementary disciplines have remained largely independent among Italian plant ecologists. Therefore, in 2021, we launched the *ITV-net* initiative, a national collaborative effort for bringing together vegetation plots and field-measured plant trait data to develop a national platform that can serve both vegetation and trait-based ecologists. In the first data call, we were able to gather trait data on two key leaf traits (i.e., Leaf Area and Specific Leaf Area) for >700 species across 1,043 georeferenced vegetation plots, complemented with species relative abundances, across eight different EUNIS habitat types. Despite this remarkable first milestone, we aim to enlarge the scope of this initiative to include more vegetation plots and functional traits across more habitat types in Italy. Here, we provide an overview of the *ITV-net* initiative and its underlying methodological details as a 'manifesto' to spread the data call to other potential contributors in the Italian community of plant ecologists. Our ultimate objective is to bridge the vegetation science and trait-based ecological research in Italy towards developing a national database of vegetation plots and plant functional traits. We believe this effort will contribute to building a solid network among Italian plant ecologists to cross the artificial boundaries of different, yet complementary, disciplines.

Keywords

Community ecology, functional traits, intraspecific trait variability, plant strategies, vegetation science

Vegetation science meets trait-based ecology

Vegetation science has changed profoundly in the last decades (Mucina 1997). The traditional Braun-Blanquet approach based exclusively on taxonomic diversity (species identities and their abundances) has been influenced by more recent conceptual and methodological advances, pushing vegetation scientists toward new frontiers (Chytrý et al. 2019; de Bello et al. 2025). The traditional taxonomic diversity approach is now routinely complemented with information on vegetation physiognomy, guilds, functional groups, and ecophysiology (Westoby 2025). Each species has measurable characteristics, i.e., traits, that are related to species performance and fitness maintenance and that

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ultimately govern ecological processes (Violle et al. 2007; Sobral 2021). In other words, following the nomenclature recently proposed by Westoby (2025), we are experiencing a shift in focus from 'trait-free' to 'trait-based' vegetation science (see also Zanzottera et al. 2021). This statement is further supported by the increasing number of articles (e.g., Bruelheide et al. 2018; Padullés Cubino et al. 2021; Kambach et al. 2023; Tordoni et al. 2024) that combine information from vegetation databases (e.g., EVA, Chytrý et al. 2016; sPlot, Sabatini et al. 2021) with trait databases (e.g., TRY; Kattge et al. 2020). However, the use of these large datasets often overlooks the role of intraspecific trait variation (ITV), since, for each species, the same average trait values are generally used in plots from different geographic locations. While this approach is extremely useful for drawing general patterns on regional and biogeographical scales (Bruelheide et al. 2018; Tordoni et al. 2022), it mostly allows top-down interpretations of ecological processes. A shift in focus to bottom-up perspectives requires generating datasets that combine the desirable features of large trait databases with information on ITV and species location, similar to other platforms already available online such as the BIEN database (https://bien.nceas.ucsb.edu/bien/).

Presenting *ITV-net*: A national initiative to bridge vegetation science and trait-based ecology

Plant ecological research in Italy is strongly rooted in 'trait-free' vegetation science and community ecology, and only recently have trait-based approaches begun to enrich the more classical ones (see Chelli et al. 2019 for a review). As a result, there is a potential pool of underlying data that, if appropriately harmonised, can provide a national platform to bridge vegetation science and trait-based research in Italy. To fill this gap, in 2021, we launched the *IT*alian *I*ntraspecific *T*rait *V*ariability *Net*work (*ITV-net*), an initiative to bring together vegetation plots and trait data with a special focus on ITV. *ITV-net* already includes more than 20 research groups (>60 researchers) and data related to 8 habitat types across the Italian peninsula. So far, we have been able to gather >8,000 individual trait values of two traits (leaf area and specific leaf area), which represent two independent dimensions of the spectrum of leaf form and function (Wright et al. 2004; Poorter et al. 2009; Díaz et al. 2016; Wright et al. 2017), for >700 species in 1,043 georeferenced vegetation plots for which species abundance is also reported (Figure 1). Thanks to its design, the *ITV-net* dataset allows users to directly match trait values at the individual level with exact geographical locations and plot-level descriptors, providing the possibility to link trait values to abiotic (e.g., climatic information in a specific geographic location) and biotic (i.e., coexisting species) variables. In this respect, we believe that the *ITV-net* dataset combines the desirable properties of available trait databases, substantially mitigating many of their inherent limitations, especially the mismatch between trait values and species occurrences. The first version of the *ITV-net* dataset has been released as an open-access data source (Chelli et al. 2025a). However, this initiative is still in its infancy, since our ultimate objective is to expand the *ITV-net* dataset in terms of both species and traits collected across diverse habitat types in the Italian peninsula. For this reason, in the following sections we outline the underlying methodology of this initiative, the first results obtained, and point to some outlooks that will hopefully persuade more research groups to share their data through this emerging national hub.

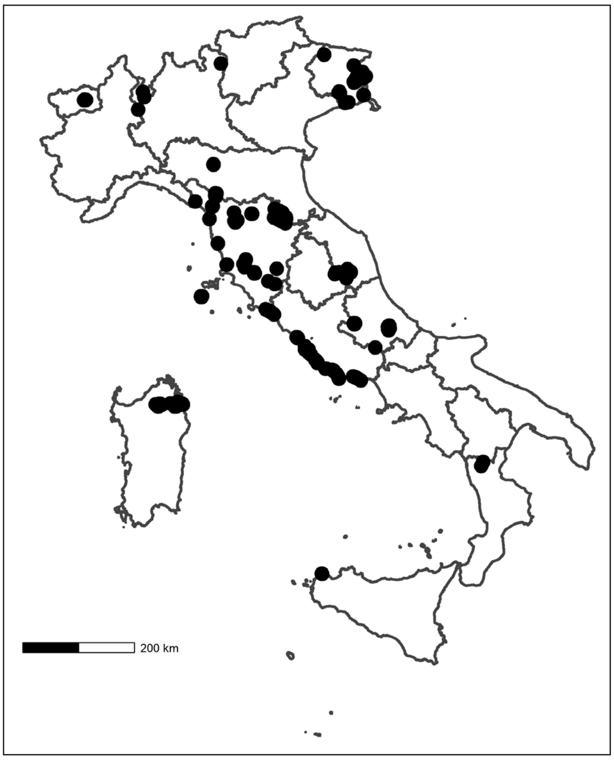

Figure 1. Geographic distribution of *ITV-net* plots across Italy and its administrative regions.

The methodology of *ITV-net*

Species and trait data

The first set of data pertains to vegetation sampling. After defining the plot with a size defined based on the vegetation type (see van der Maarel 2005), all species within it are recorded along with their percentage of cover. Only taxa at species level are allowed. Further, since measuring all species within the plot is usually unfeasible (e.g., time limitations, presence of rare or protected species), measuring at least those species whose relative cover cumulatively accounts for approximately 80% of the total plot coverage represents a good practice to maintain high accuracy of trait information collected at the community level (Májeková et al. 2016). For example, given a plot with three species: species A (30%), species B (20%), and species C (5%), with a total cover of 55% deriving from the sum of species cover, the relative contribution of each species is calculated as follows: (30/55) × 100 = 54%, (20/55) × 100 = 36%, and (5/55) × 100 = 9%. In this case, it is enough to measure traits for only species A and species B, as their cumulative cover meet the 80% threshold considered in this database. This methodological approach is based on the 'biomass-ratio hypothesis' (Grime 1998), which suggests that the effect of species' traits on ecosystems is proportional to their relative abundance (Pakeman and Quested 2007; Májeková et al. 2016).

Once the species are identified and their relative abundance is recorded, traits should be measured on an adequate number of replicates for each species to include the highest possible proportion of ITV according to widely recognized standardized measurement protocols (e.g., Perez-Harguindeguy et al. 2016; Freschet et al. 2021). For example, for woody species, 5 leaves from 5 individuals have been shown to be an optimal minimum sample size for leaf traits such as specific leaf area (SLA) and leaf osmotic potential at full turgor (π_0) (Petruzzellis et al. 2017). However, this number could vary according to the life form and trait considered, and we always advise checking the appropriate sample size suggested in standardised protocols (e.g., Perez-Harguindeguy et al. 2016). For the *ITV-net* initiative, at least three independent measurements are required. These must be taken by three different individuals within the plot or, if necessary, from nearby areas if there are not enough individuals within the plot. For caespitose species, measurements should be taken from different tussocks, while for clonal species, more distant ramets are preferred to minimise the probability of sampling the same individual. However, in some cases, such as for root or clonal traits, we highly recommend following specific recently proposed protocols (Klimešová et al. 2019; Freschet et al. 2021).

We note that in the first data compilation, some datasets provided trait values at the individual level only for one plot, and the same trait value was then kept constant across sampled plots (i.e., extensive traits collection). While these kinds of data can still be useful depending on how trait values are aggregated (e.g., Puglielli et al. 2024), and are properly flagged in the ITV-net dataset (see Chelli et al. 2025b), for future developments we recommend that contributors provide trait values in each plot where a species occurs (i.e., intensive traits collection).

To ensure consistency in the species names recorded by different contributors, it is essential to standardize the nomenclature using a common checklist. Therefore, species names should be provided based on two sources: i) consulting the Portal to the Flora of Italy (https://dryades.units.it/floritaly/) following the national checklists for native and alien species; ii) the international checklist from the World Flora Online (https://www.worldfloraonline.org/) to guarantee a broader use of the database at international level. See Figure 2 for a summary of the required data.

Metadata

Auxiliary information at the plot level is pivotal to providing context to the trait values included in the *ITV-net* dataset. For this reason, during the first data compilation, we asked contributors to provide a set of plot-level information as follows:

Plot coordinates: Latitude and longitude data expressed in decimal degrees (datum WGS84) and recorded at the centre of the plot.

Plot size: expressed in m^2. We do not provide exact values of the area since the choice could depend on the vegetation type considered. However, this information is essential, for instance, to control for the effect of plot size in statistical models (Sabatini et al. 2022).

Plot topographic information: We require providing information on elevation (m a.s.l.), slope (°), and aspect (°). Traits can show remarkable variation depending on the plot topography, providing key information to interpret associated trait records.

Sampling year: This information is key to addressing research questions on temporal trends of trait variation or to interpreting trait records sampled in years with

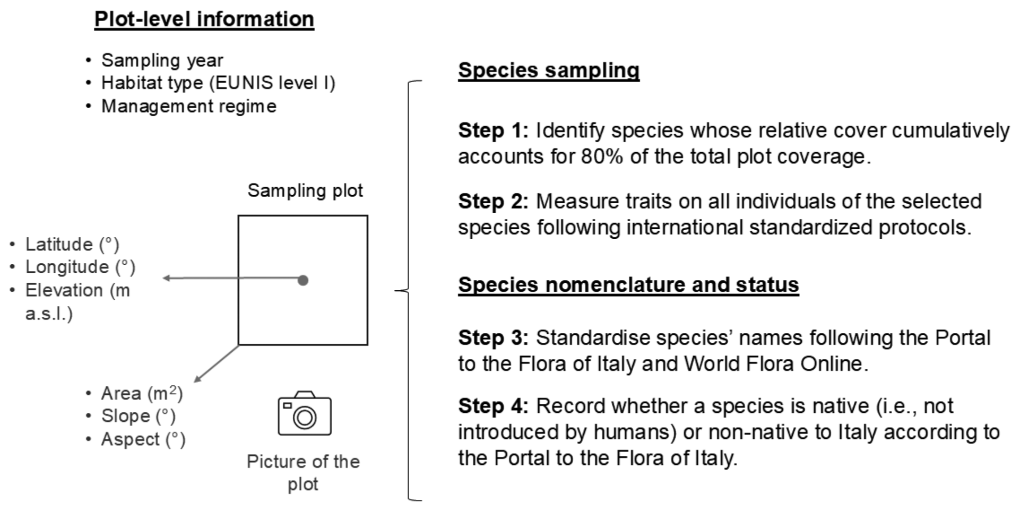

Figure 2. Outline of the data and steps required to contribute to *ITV-net*.

peculiar climatic trends (e.g., extreme droughts such as during the year 2023).

Habitat type: There exist multiple classification systems to assign trait records to a specific habitat type. We decided to use a more general classification system, the first level of the EUNIS habitat classification (Chytrý et al. 2020). The EUNIS classification was preferred in view of extending the initiative beyond the Italian borders and allowing users from outside Italy to clearly identify the habitat types included in the dataset. The choice of level I is mostly related to the need to maximise the number of records per habitat type.

Management regime: plot management is essential to avoid potential confounding effects on trait records. For example, frequent grazing or burning might significantly change the species and trait composition of a community. If there is no management regime, contributors are encouraged to classify the plot as 'natural'. In cases where multiple management regimes are present, the most common, or all of them, can be provided.

Status: For each species in the plot, contributors should indicate whether they are native (i.e., not introduced by humans) or non-native to Italy (neophytes *vs.* archaeophytes) according to the Portal to the Flora of Italy. If possible, also specify if native species have recently colonized the area due to human-induced environmental change ("neonative" species *sensu* Essl et al. 2019).

Notes: the previous points are far from providing an exhaustive list of metadata. For this reason, we encourage contributors to provide any additional metadata that can help to provide context to the associated trait records. Information in the Notes section might include information such as disturbance conditions, shading, whether the plot is part of a study of natural gradient or a manipulative experiment, or any other information that is considered relevant to interpreting the trait records.

Picture: At least one picture of the plot.

Dataset custodians: since the data contribution will be acknowledged by co-authorship of the articles produced under the *ITV-net* initiative, we limit the number of custodians to a maximum of three per dataset. This also allows us to match the datasets to the contributors for quality checks and updates.

We provide a template file reporting the headers of a potential data contribution file, and we encourage sending data to the itv.collaboration@gmail.com to contribute to the growth of the ITV-net dataset (Suppl. material 1).

Ongoing analyses under the *ITV-net* initiative

To date, several studies have shown that the magnitude of ITV with respect to total trait variation is not negligible (Lecerf and Chauvet 2008; Messier et al. 2010; de Bello et al. 2011; Siefert et al. 2015; Des Roches et al. 2018; Wong and Carmona 2021). The recognised importance of ITV has called for the development of practical and theoretical frameworks to account for ITV in trait-based studies (Albert et al. 2010; Albert et al. 2011; Moran et al. 2016; Wong and Carmona 2021). In this light, under the ITV-net initiative, we have already started to address three still unresolved issues related to the inclusion of ITV in trait-based studies.

First, most of the previous analyses calculated the magnitude of ITV trait by trait (Messier et al. 2010; Siefert et al. 2015) providing valuable insights on the traits or functions more or less prone to intraspecific variation, but missing a fundamental open issue in plant ecology, that is, whether the inclusion of ITV could affect the shape and dimensions of the functional space describing the spectrum of ecological strategies at the species or population levels. Indeed, plant ecological strategies are better described by multi-traits analyses, which allow us to highlight the main trade-offs underlying different plant ecological strategies (e.g., the Leaf Economic Spectrum, Wright et al. 2005), and to draw the spectrum of plant form and functions at the global level (Díaz et al. 2016). Recent studies showed that the inclusion of ITV could affect both trait–trait coordination, as some trait–trait relationships observed between species are not consistent within species, and trait space dimensionality, which could be potentially expanded when including ITV (Griffin-Nolan and Sandel 2023). However, these studies tested one trait dimension at a time, while plant ecological strategies are usually defined by a set of independent axes of trait variation (Westoby 1998; Laughlin 2023). In Puglielli et al. (2024), we provided a new framework for including ITV into trait space analyses to test whether the inclusion of ITV could reshape the trait space defined by two fundamental axes of the global spectrum of leaf form and function, i.e., leaf size and leaf mass per area, using a subset of the ITV-net dataset. We found that the inclusion of ITV affected both the dimension and the shape of the functional space, since ITV increased the variance explained by the two axes of trait variation, caused a rotation of these two axes, and altered the positioning of the species within the functional space. However, the magnitude of these effects was relatively small and, importantly, context dependent, varying according to the habitat considered (e.g., coastal dunes were the ones displaying the greatest ITV).

Another unresolved issue in plant ecology is when and how to consider ITV in trait-based studies. Ideally, ITV should be considered in every possible context, but measuring traits in many individuals per species and site is rarely done. Albert et al. (2011) provided a theoretical framework, based on the spatial variance hypothesis, whose core tenet is that ITV tends to saturate as the spatial scale of the study widens, while between-species trait variation increases with increasing spatial scale and saturates only at the global level. To date, only a few studies have tested this framework or the assumptions at the basis of the spatial variance hypothesis (e.g., Siefert et al. 2015), and a consensus is lacking. In this light, the second aim of the ITV-net initiative is to test the spatial variance hypothesis at three spatial scales (i.e., plot, habitat, and macro-area).

A third issue, still partially addressed in trait-based studies, is how ITV is integrated into the framework of assembly rules (Jung et al. 2010; Bricca et al. 2022; Ferrara et al. 2024). Assembly rules refer to mechanisms regulating species co-existence (Götzenberger et al. 2012). Over the years, research has identified several mechanisms that, acting on a species pool, progressively select only a set of species that are able to persist in a local plant community (de Bello et al. 2013). These mechanisms are generally interpreted in terms of the "habitat filtering theory" (Keddy 1992), stating that environmental conditions select only species with similar trait values that confer functional advantages under given conditions.

As such, the local plant community is composed of species with a higher degree of niche overlapping (i.e., similar trait values). However, other mechanisms can limit the similarity between coexisting species, especially those related to competitive exclusion. This is the case of the "limiting similarity theory" (MacArthur and Levins 1967). Environmental filtering and competition are not mutually exclusive, being the first more prominent at a large spatial scale and the latter at a more local scale. However, while these mechanisms have been widely assessed in the case of fixed traits, how intraspecific trait variation can be regulated by these mechanisms is still largely unknown. According to theoretical predictions (see Violle et al. 2012), at broad spatial scales, interspecific trait variation (or between-species trait variation) is expected to be larger than ITV, while ITV becomes more important as the study scale decreases. Broad-scale filters select species based on average trait values, whereas finer-scale filters select individuals within species expressing trait values that match local conditions. In this context, leveraging the database collected under the ITV initiative, we aim to disentangle the contribution of ITV when assessing community assembly rules across different habitats and spatial scales.

Future outlook on the integration of ITV with vegetation science

The *ITV-net* initiative represents a further step toward a complete integration of vegetation science and trait-based ecology, especially in the Italian research landscape. However, to enhance its ecological relevance, future efforts should prioritise the inclusion of traits representing additional dimensions of plant form and function, such as plant height, belowground traits related to fine root (e.g., specific root length, root tissue density; Freschet et al. 2021; Carmona et al. 2021) and main storage organ (e.g., belowground dry matter content; de Bello et al. 2012; Bricca et al. 2023), clonal traits (e.g, lateral spread; Chelli et al. 2024), and hydraulic traits (e.g., turgor loss point; Anderegg et al. 2016; Tordoni et al. 2020; Petruzzellis et al. 2021). These traits are fundamental for a more holistic understanding of resource acquisition, stress tolerance, and reproductive strategies, ultimately providing a more comprehensive assessment of functional characteristics and ecosystem processes. In particular, the focus on belowground plant compartments has been highlighted by vegetation scientists as a future challenge for the advancement of the field (Yannelli et al. 2022). Another crucial advancement for *ITV-net* is the incorporation of spatio-temporal variation in intraspecific trait variability. Plant traits are intrinsically dynamic, varying with phenological stages, seasonal shifts, and environmental variation (Puglielli and Varone 2018; Puglielli et al. 2019; Puglielli 2019; Carmona et al. 2021), and these aspects can be exacerbated by climate change (Griffin-Nolan et al. 2019; Pavanetto et al. 2025). Collecting data across seasons and years will shed light on how ITV mediates plant responses to changing climates and disturbances, providing a more nuanced view of plant strategies.

In conclusion, the ultimate goal of *ITV-net* is to evolve into a dynamic and scalable platform that will potentially integrate species characteristics with fine-scale information about communities. By especially encouraging contributions for under-represented locations or habitats and for traits not routinely included in trait-based studies, we seek to address key gaps in trait-based ecology and biodiversity research. Finally, the initiative can be exported outside the Italian borders, thereby increasing its overall scope.

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Supplementary material 1

Template file reporting the headers of a potential data contribution file

Authors: Alessandro Bricca, Stefano Chelli, Francesco Petruzzellis, Giacomo Puglielli, Enrico Tordoni

Data type: xlsx

Explanation note: Occurences, plant traits, metadata.

Link: https://doi.org/10.3897/ved.154284.suppl1