



Shedding light on typical species: implications for habitat monitoring

Gianmaria Bonari¹, Edy Fantinato², Lorenzo Lazzaro³, Marta Gaia Sperandii^{4,5}, Alicia Teresa Rosario Acosta⁵, Marina Allegrezza⁶, Silvia Assini⁷, Marco Caccianiga⁸, Valter Di Cecco⁹, Annarita Frattaroli⁹, Daniela Gigante¹⁰, Giovanni Riviaccio¹¹, Giulio Tesei⁶, Barbara Valle⁸, Daniele Viciani³, Giulia Albani Rocchetti⁵, Claudia Angiolini¹², Emilio Badalamenti¹³, Davide Barberis¹⁴, Matteo Barcella⁷, Giuseppe Bazan¹⁵, Andrea Bertacchi¹⁶, Rossano Bolpagni¹⁷, Federica Bonini¹⁰, Alessandro Bricca¹⁸, Gabriella Buffa², Mariasole Calbi³, Silvia Cannucci¹⁹, Luigi Cao Pinna⁵, Maria Carmela Caria²⁰, Emanuela Carli²¹, Silvia Cascone⁵, Mauro Casti²², Bruno Enrico Leone Cerabolini²³, Riccardo Copiz²⁴, Maurizio Cutini⁵, Leopoldo De Simone¹², Andrea De Toma⁵, Michele Dalle Fratte²³, Luciano Di Martino²⁵, Romeo Di Pietro²⁶, Leonardo Filesi²⁷, Bruno Foggi³, Paola Fortini²⁸, Roberto Gennaio²⁹, Gabriele Gheza³⁰, Michele Lonati¹⁴, Andrea Mainetti¹⁴, Marco Malavasi³¹, Corrado Marcenò³², Carla Micheli³³, Chiara Minuzzo³⁴, Michele Mugnai³, Carmelo Maria Musarella³⁵, Francesca Napoleone³⁶, Ginevra Nota¹⁴, Giovanna Piga³⁷, Marco Pittarello¹⁴, Ilaria Pozzi³⁸, Safiya Praleskouskaya³⁹, Francesco Rota¹, Giacomo Santini¹², Simona Sarmati^{5,12}, Alberto Selvaggi⁴⁰, Giovanni Spampinato³⁵, Adriano Stinca⁴¹, Francesco Pio Tozzi²⁸, Roberto Venanzoni³⁹, Mariacristina Villani⁴², Katia Zanatta⁴³, Magda Zanzottera⁸, Simonetta Bagella^{11,20}

1 Free University of Bozen-Bolzano, Department of Science and Technology, Piazza Università 5, I-39100, Bolzano, Italy

2 University Ca' Foscari of Venice, Department of Environmental Sciences, Informatics and Statistics, Via Torino 155, I-30172, Venezia Mestre, Italy

3 University of Florence, Department of Biology, Via La Pira 4, I-50121, Firenze, Italy

4 Centro de Investigaciones sobre Desertificación (CSIC-UV-GV), Carretera Moncada-Náquera Km 4.5, E-46113 Moncada, Spain

5 Roma Tre University, Department of Sciences, Viale G. Marconi 446, I-00146 Roma, Italy

6 Marche Polytechnic University, Department of Agricultural, Food and Environmental Sciences, Via Breccie Bianche, I-60131, Ancona, Italy

7 University of Pavia, Department of Earth and Environment Sciences, via S. Epifanio 14, I-27100, Pavia, Italy

8 University of Milan, Department of Biosciences, via Celoria 26, I-20133, Milano, Italy

9 University of L'Aquila, Department of Life, Health and Environmental Sciences, Via Vetoio, I-67100 Coppito, L'Aquila, Italy

10 University of Perugia, Department of Agricultural, Food and Environmental Sciences, Borgo XX giugno 74, I-06121, Perugia, Italy

11 University of Sassari, Desertification Research Centre, Via de Nicola, I-07100, Sassari, Italy

12 University of Siena, Department of Environment, Earth and Physical Sciences, Via P.A. Mattioli 4, I-53100, Siena, Italy

13 University of Palermo, Department of Agricultural, Food and Forest Sciences, Viale delle Scienze 13, I-90128, Palermo Italy

14 University of Turin, Department of Agricultural, Forest and Food Sciences (DISAFA), Largo P. Braccini 2, I-10095, Grugliasco, Torino, Italy

15 University of Palermo, Department of Biological, Chemical and Pharmaceutical Sciences and Technologies (STEBICEF), Via Archirafi 38, I-90123, Palermo, Italy

16 University of Pisa, Department of Agricultural, Food and Agro-Environmental Sciences, Via del Borghetto 80, I-56124, Pisa, Italy

17 University of Parma, Department of Chemistry, Life Sciences and Environmental Sustainability (SCVSA), Parco Area delle Scienze 33/a, I-43124, Parma, Italy

18 University of Camerino, School of Biosciences and Medicine Veterinary, Via Pontoni 5, I-62032, Camerino, Macerata, Italy

19 Strada Altichiari Cannuccio 14, I-53035, Monteriggioni, Italy

20 University of Sassari, Department of Chemistry and Pharmacy, Via Vienna 2, I-07100, Sassari, Italy

21 ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale), via Vitaliano Brancati 48, I-00144, Roma, Italy

22 via del Sole 17, I-09126, Cagliari, Italy

23 University of Insubria, Department of Biotechnologies and Life Sciences, via J.H. Dunant 3, I-21100 Varese, Italy

24 Via Casilina Sud 22, I-03100, Frosinone, Italy

25 Ente Parco Nazionale della Maiella, Ufficio Monitoraggio e Conservazione delle Biodiversità vegetale, Via Badia 28, I-67039, Sulmona, L'Aquila, Italy

26 Sapienza University of Rome, Department of Planning, Design, and Technology of Architecture (PDTA), Via Flaminia 72, I-00196, Roma, Italy

27 Iuav University of Venice, Dipartimento di Culture del progetto; Santa Croce 191 Tolentini, I-30135, Venezia, Italy

28 University of Molise, Department Bioscience and Territory, Contrada Fonte Lappone, I-86090, Pesche, Isernia, Italy

29 ARPA Puglia, Via Antonio Miglietta 2, I-73100, Lecce, Italy

30 University of Bologna, Department of Biological, Geological and Environmental Sciences, Via Irnerio 42, I-40126, Bologna, Italy

31 Czech University of Life Sciences Prague, Faculty of Environmental Sciences, Department of Spatial Sciences, Kamycka 129, CZ-16500, Prague 6, Czech Republic

32 Masaryk University, Department of Botany and Zoology, Kotlářská 2, CZ-61137, Brno, Czech Republic

33 ENEA, Italian National Agency for New Technologies, Energy and Sustainable Economic Development Department of Energy Technologies and Renewable Sources, Research Centre Casaccia, I-2400/00123, Roma, Italy

34 Regione Serramonte 10, I-10010, Andrate, Torino, Italy

35 Mediterranean University of Reggio Calabria, Department of Agriculture, loc. Feo di Vito snc, I-89122, Reggio Calabria, Italy

36 Sapienza University of Rome, Department of Environmental Biology, Piazzale Aldo Moro 5, I-00185, Roma, Italy

37 University of Sassari, Department of Agriculture, Piazza Università 21, I-07100, Sassari, Italy

38 Independent Researcher and ecologist for Conservatoire d'espaces naturels, Auvergne FR-15300, France

39 University of Perugia, Department of Chemistry, Biology and Biotechnology, Polo Didattico, via del Giochetto 16, Ed. A, I-06122, Perugia, Italy

40 Institute for Timber Plants and the Environment, Corso Casale 476, I-10132, Torino, Italy

41 University of Campania Luigi Vanvitelli, Department of Environmental, Biological and Pharmaceutical Sciences and Technologies, Via A. Vivaldi 43, I-81100, Caserta, Italy

42 University of Padua, Botanical Garden of Padua, Via Orto Botanico 15, I-35121, Padova, Italy

43 Via Colombero 42, I-31040, Gaiavera del Montello, Treviso, Italy

Corresponding author: Barbara Valle (barbara.valle@unimi.it)

Subject editor: Gianluigi Bacchetta ♦ Received 8 June 2021 ♦ Accepted 21 June 2021 ♦ Published 30 June 2021

Abstract

Habitat monitoring in Europe is regulated by Article 17 of the Habitats Directive, which suggests the use of typical species to assess habitat conservation status. Yet, the Directive uses the term “typical” species but does not provide a definition, either for its use in reporting or for its use in impact assessments. To address the issue, an online workshop was organized by the Italian Society for Vegetation Science (SISV) to shed light on the diversity of perspectives regarding the different concepts of typical species, and to discuss the possible implications for habitat monitoring. To this aim, we inquired 73 people with a very different degree of expertise in the field of vegetation science by means of a tailored survey composed of six questions. We analysed the data using Pearson's Chi-squared test to verify that the answers diverged from a random distribution and checked the effect of the degree of experience of the surveyees on the results. We found that most of the surveyees agreed on the use of the phytosociological method for habitat monitoring and of the diagnostic and characteristic species to evaluate the structural and functional conservation status of habitats. With this contribution, we shed light on the meaning of “typical” species in the context of habitat monitoring.

Keywords

diagnostic and characteristic species, habitat monitoring, keystone species, Natura 2000, plant community, structure and functions, typical species, 92/43/EEC Directive

Introduction

In the Anthropocene, many ecosystems are increasingly at risk due to the concurrent action of a set of drivers such as habitat loss, fragmentation, invasive species and pollution, that are altering ecosystem structure and functioning, while threatening their long-term persistence and capability to provide essential ecosystem services (IPBES 2019). Accordingly, monitoring changes in natural ecosystems is a top priority in global conservation agendas to anticipate ecological tipping points, ultimately preventing ecosystem collapse (Balmford 2005; Jongman 2013; Gigante et al. 2018), as already pointed in the Biodiversity Strategy (https://ec.europa.eu/environment/nature/biodiversity/strategy/index_en.htm).

In Europe, ecosystem monitoring is regulated by the Habitats Directive (Art. 17 of the 92/43/EEC), and it

is mostly done at the habitat level (Lengyel et al. 2008a; 2008b; Campagnaro et al. 2019), a key component of biodiversity (Legg and Nagy 2006; Bunce et al. 2013; Proença et al. 2017). The Habitats Directive requires the Member States to report, every six years, on the conservation status of natural and semi-natural habitats listed in Annex I (European Commission 1992), to verify the effectiveness of EU policies in terms of biodiversity conservation (Evans and Arvela 2011; DG Environment 2017). According to this Directive (European Commission 1992), largely considered as the cornerstone of Europe's nature conservation, the status of a habitat type is defined based on four criteria: area, range, structure and functions, future prospects.

While habitat area, range and future prospects are assessed at biogeographical level, the “structure and functions” parameter can be monitored at the local level starting from field data, trying to minimise the degree

of subjectivity (Carli et al. 2018; Tsiripidis et al. 2018). Whereas structures describe the physical components of a habitat type (e.g., trees in a woodland), functions highlight the ecological processes occurring at various temporal and spatial scales (Evans and Arvela 2011; DG Environment 2017). However, the evaluation of the “structure and functions” parameter strongly relies on the assessment of conservation status of typical species; indeed, according to the Habitats Directive, for a habitat type to be considered in favourable conservation status, both its structure and functions and its typical species should be at a favourable conservation status (European Commission 1992). Following Evans and Arvela (2011), typical species “should be selected to reflect favourable structure and functions of the habitat type”, meaning that they should be at the same time: i) good indicators for favourable habitat quality; ii) exclusive of the habitat or present over a large part of the habitat range; iii) sensitive to changes in the conditions of the habitat. Despite that, the Habitats Directive itself uses the term “typical” species but does not provide a definition, either for its use in reporting or for its use in impact assessments. Some Member States proposed to start from vegetation databases, with data recorded on the field, to define typical species lists (Maciejewski 2010; Tsiripidis et al. 2018). Recently, a list of statistically-derived characteristic species combinations for EUNIS habitat types have been published (Chytrý et al. 2020).

In Italy, the evaluation of structure and functions of habitat types, has usually been carried out relying on typical species, identified by experts. They are summarized in the “physiognomic reference combination” on the online Italian version manual for the interpretation of habitats (Biondi et al. 2009; Biondi 2013). Additionally, Gigante et al. (2016) pointed out some criteria for selecting the typical species *sensu* Habitats Directive, partially overcoming the lack of a unique definition. They suggested that typical species can be recognized only in species-poor habitats or when habitats are characterised by a low number of physiognomy-shaping genera and species; however, in the case of species-rich habitats, the whole floristic pool should be considered as the best proxy for assessing the conservation status, thus overcoming the use of typical species. These criteria are explained, and the resulting species lists proposed, in Angelini et al. (2016).

In the first place, it is not clear yet to what extent phytosociology and other disciplines, such as functional ecology, can be used to identify typical species. Diagnostic and characteristic species, as defined in the phytosociological method (Braun-Blanquet 1932), can be used to identify typical species following the second criterion (“species only found in the habitat or which are present over a large part of the habitat’s range”; Evans and Arvela 2011). On the other hand, they may not meet the other two criteria, i.e., they may not be good indicators of habitat quality and changes. At the same time, typical species selected only through a functional approach can eventually warn about habitat quality and changes, while failing at distinguishing one habitat from another. As a consequence, the use of dif-

ferent approaches and definitions might lead to inconsistencies in the evaluation of habitats’ conservation status.

A further potential approach that might be valuable for habitat monitoring advocates the use of keystone species, widely applied in ecology, as typical species. Keystone species play critical ecological roles that are of greater importance than one would predict from their abundance (Power et al. 1996); indeed, they have a disproportionate impact, in relation to their number or biomass, on the organization of a biological community. The loss of a keystone species may have far-reaching consequences for the community (Primack 2018). Therefore, these species have exceptionally large effects on communities and ecosystems through processes such as trophic interactions, habitat modification, and mutualism (Grime 1998; de Visser et al. 2013).

An additional issue is the spatial scale at which typical species should be identified. By definition, typical species should be exclusive of a given habitat, but they should reflect favourable structure and functions (Evans and Arvela 2011; Oosterlynck et al. 2013). Yet, it might not always be possible to identify unique links between habitats and functions, as the realization of some functions strictly depends on the co-occurrence of multiple habitats interconnected at the landscape scale (e.g., Betts et al. 2019; Hackett et al. 2019).

The Italian Society for Vegetation Science (SISV) is not novel to collectively contribute to aspects related to habitat monitoring (Gigante et al. 2016; 2018). In October 2020, an online workshop was organized by SISV to shed light on the diversity of perspectives regarding the concepts of “typical”, “diagnostic”, “characteristic” and “keystone” species, to discuss the possible implications for habitat monitoring. Specifically, the workshop addressed the following questions: (i) Are diagnostic and characteristic species informative about the structural and functional conservation status of habitats? In other words, might we use them as typical species? (ii) Are diagnostic and characteristic species used to assess conservation status dependent on specific habitats? (iii) Diagnostic, characteristic and typical species: how much do they overlap (conceptually and practically)? (iv) What about keystone species? Might they be used as typical species too? (v) Does scale matter for the definition of typical species?

This study aims to provide insights on these topics, by combining different points of view of researchers and professionals of vegetation science to give a shared interpretation on typical species and the implications for habitat monitoring.

Methods

Survey data collection

We aimed to acquire a consistent overview regarding specific topics’ opinions such as “diagnostic”, “characteristic” and “typical” species for habitat monitoring throughout the whole potential audience of Italian scientists and pro-

professionals dealing with vegetation science. To this aim, before the workshop, SISV organisers sent out a tailored survey addressing confirmed workshop participants (hereafter, 'surveyees'). Surveyees included persons with a very different degree of expertise in habitat monitoring, spanning from students and young scientists to experienced professionals and recognized vegetation scientists. The survey was composed of 8 questions with hybrid possibilities of multiple-choice, binary and open answers (see Tab. 1 for the questions and possible answers). The first three questions (i.e., Q1-Q3) were intended to account the different levels of expertise among surveyees and their agreement on the methods used for habitat monitoring. Q1 aimed at a self-evaluation of experience degree, and Q2 asked whether the surveyee had previously used the phytosociological method in habitat monitoring; Q3 investigated the opportunity of using the phytosociological method to perform habitat monitoring. Questions Q3 to Q8 (except for Q6) were developed in a "Likert scale" (Likert 1932) with 5 ordered and symmetric levels of agreement, ranging from "strongly disagree" to "strongly agree". In addition, since some questions might have required further explanation than a categorical choice, we accompanied all questions by the possibility of adding a brief description. This strategy allowed us to (i) have a general overview of the surveyees' opinions, (ii) synthesize the open questions prior to the workshop, and (iii) during the workshop, start the discussion based on the already-retrieved data, thus optimizing the limited online time at disposal, and making the whole debate more focused and effective.

Workshop structure

During the workshop, the results of the survey were presented in raw form (i.e., with no statistical analysis), and discussed among participants. Starting from this discussion, we attempted to find shared views and solutions to the raised issues. To this end, several contributions and case studies presented by the participants helped to shed light through direct monitoring experiences. We summarize the main conclusions together with the most relevant issues emerged during the debate.

Data analysis

We analyzed the results of all the questions (Q1-Q8) by means of a Pearson's Chi-squared test with simulated p-value (based on 9999 randomizations) to verify that the answers diverged from a random distribution. Then, we checked the effect of the surveyees' experience on the answers Q3-Q8. We used an Asymptotic Linear-by-Linear Association Test (Agresti 2002), to verify whether these answers (Q3-Q8) were influenced by the ordered level of surveyees' experience (i.e., whether increasing levels of expertise affected the surveyees opinion). This test allows comparing data expressed in any ordinal (i.e., ordered) scale. We used two-tailed tests, with no specific direction of the relationship among expertise and answer output. Moreover, we evaluated with a Pearson's Chi-squared test with simulated p-value (based on 9999 randomizations) whether having already used the phytosociological method to perform habitat monitoring affected the surveyed opinion on the other questions (Q3-Q8).

Table 1. Questions and possible answers provided to the surveyees. The Q3-Q8 answers followed the "Likert scale" (Likert 1932).

N	Question	Possible answers					
Q1	Level of expertise on habitat monitoring	No experience	Little experience	Medium experience	Solid experience		
Q2	Did you already use the phytosociological method to perform habitat monitoring?	Yes	No				
Q3	Do you agree with the use of phytosociological method to perform habitat monitoring?	Strongly disagree	Disagree	Neither agree nor disagree	Strongly agree	Agree	
Q4	Are diagnostic and characteristic species informative about structural and functional conservation status of habitats?	Strongly disagree	Disagree	Neither agree nor disagree	Strongly agree	Agree	
Q5	Is the use of diagnostic and characteristic species for assessing conservation status dependent on specific habitats?	Strongly disagree	Disagree	Neither agree nor disagree	Strongly agree	Agree	
Q6	Diagnostic, characteristic and typical species: how much do they overlap (conceptually and practically)?	Slightly	Moderately	Strongly			
Q7	Keystone species. Can keystone species be used as typical species?	Strongly disagree	Disagree	Neither agree nor disagree	Strongly agree	Agree	
Q8	Does scale matter for the definition of typical species?	Strongly disagree	Disagree	Neither agree nor disagree	Strongly agree	Agree	

Results of the survey

Overall, 73 people participated in the questionnaire survey and 104 in the workshop. Among surveyees, 17 (23%) stated to have solid experience in habitat monitoring, whereas a comparable number had little or medium experience (23 and 21, respectively; i.e., 32% and 29%; Fig. 1A). Only 12 (16%) participants had no experience. About 71% of the surveyees had already used the phytosociological method to perform habitat monitoring (Fig. 1B).

Answers to all questions, except Q1, showed significant differences in the frequencies among the responses provided (Tab. 2).

Most of the surveyees (77%) agreed with the use of the phytosociological method to perform habitat monitoring, while very few (5.5%) disagreed (Fig. 1C). Also, the majority of the surveyees (59%) agreed that diagnostic and characteristic species are informative about the structural and functional conservation status of habitats, a substantial proportion was undecided (around 30%), while a smaller rate disagreed (about 11%; Fig. 1D).

Almost all surveyees (about 84%) acknowledged that the use of diagnostic and characteristic species for assessing conservation status is dependent on specific habitats (Fig. 1E).

The overlapping between diagnostic, characteristic and typical species was strongly recognized by 24% and moderately acknowledged by 71% of the surveyees (Fig. 1F).

The answers on using keystone species as typical species had an unclear pattern (Fig. 1G). About 50% of surveyees agreed that keystone species could be used as typical species. There was a substantial proportion of undecided (around 29%), and about 22% disagreed.

The scale for the definition of typical species resulted important (Fig. 1H), showing a widespread agreement among surveyees (68%), while 22% of the surveyees were undecided (22%) or disagreed (11%).

The Asymptotic Linear-by-Linear Association Test revealed that only Q5 was affected by the level of expertise of the surveyees, while for all the other answers, the association was not significant (Tab. 3). Particularly, experienced surveyees supported more consistently than others that the use of diagnostic and characteristic species for assessing conservation status depends on the study habitat (Fig. 2). Furthermore, we detected no effect of the previous use of the phytosociological method in habitat monitoring (Tab. 3).

Discussion from the workshop

The answers to the questionnaire highlighted a substantially shared point of view on the debated topic, though diverging opinions on some specific issues emerged.

We present them by summarizing the main messages, highlighting pros and cons, and offering proactive ideas to shed light on the meaning and use of typical species for habitat monitoring.

Table 2. Results of Pearson's Chi-squared test with simulated p-value (based on 9999 randomizations) to verify that the answers diverged from a stochastic distribution.

Question	Chi Square statistic	p-value
Q1	4.53	0.216
Q2	13.16	<0.001
Q3	57.75	<0.001
Q4	66.47	<0.001
Q5	69.92	<0.001
Q6	47.75	<0.001
Q7	21.51	<0.001
Q8	31.22	<0.001

Table 3. Results of the Asymptotic Linear-by-Linear Association Test to verify whether contributors' answers were influenced by their level of expertise (Q1), and of the Pearson's Chi-squared test with simulated p-value (based on 9999 randomizations) for the effect of the previous use of phytosociological method in habitat monitoring (Q2).

	Test on the effect of Q1		Test on the effect of Q2	
	Test statistic (Z)	p-value	Test statistic (X ²)	p-value
Q3	-1.063	0.288	6.431	0.130
Q4	0.461	0.645	1.312	0.897
Q5	-2.774	0.006	3.667	0.303
Q6	-1.630	0.103	3.147	0.214
Q7	-0.450	0.653	3.547	0.494
Q8	-0.186	0.853	2.595	0.475

During the workshop, a large part of the discussion focused on the phytosociological method. Surveyees agreed that using the floristic-vegetation sampling, i.e., the phytosociological method *sensu* Braun-Blanquet (1932) and further updatings (Dengler et al. 2008; Biondi 2011; Guarino et al. 2018), to perform habitat monitoring, has undoubted strengths. The use of phytosociological relevés provides detailed information on the composition and structure of plant communities, it is widely used and allows cost-effective habitat monitoring. Indeed, the Italian manual for habitat monitoring suggested using it for field (Angelini et al. 2016). However, though the phytosociological relevé has wide approval among participants, its acceptance is not unanimous. The concerns are related to various aspects for which adequate solutions were proposed during the discussions. The phytosociological method does not consider other taxonomic groups (e.g., animal taxa) that, being involved in specific ecosystem functions, might provide crucial information on the conservation status of a habitat (Bland et al. 2016). Additionally, the participants to the workshop reported that the phytosociological method, in accordance with the original aim of the discipline, i.e., the description and typification of vegetation units (Braun-Blanquet 1932), is based on a partially subjective sampling protocol linked to the selection of physiognomically and structurally homoge-

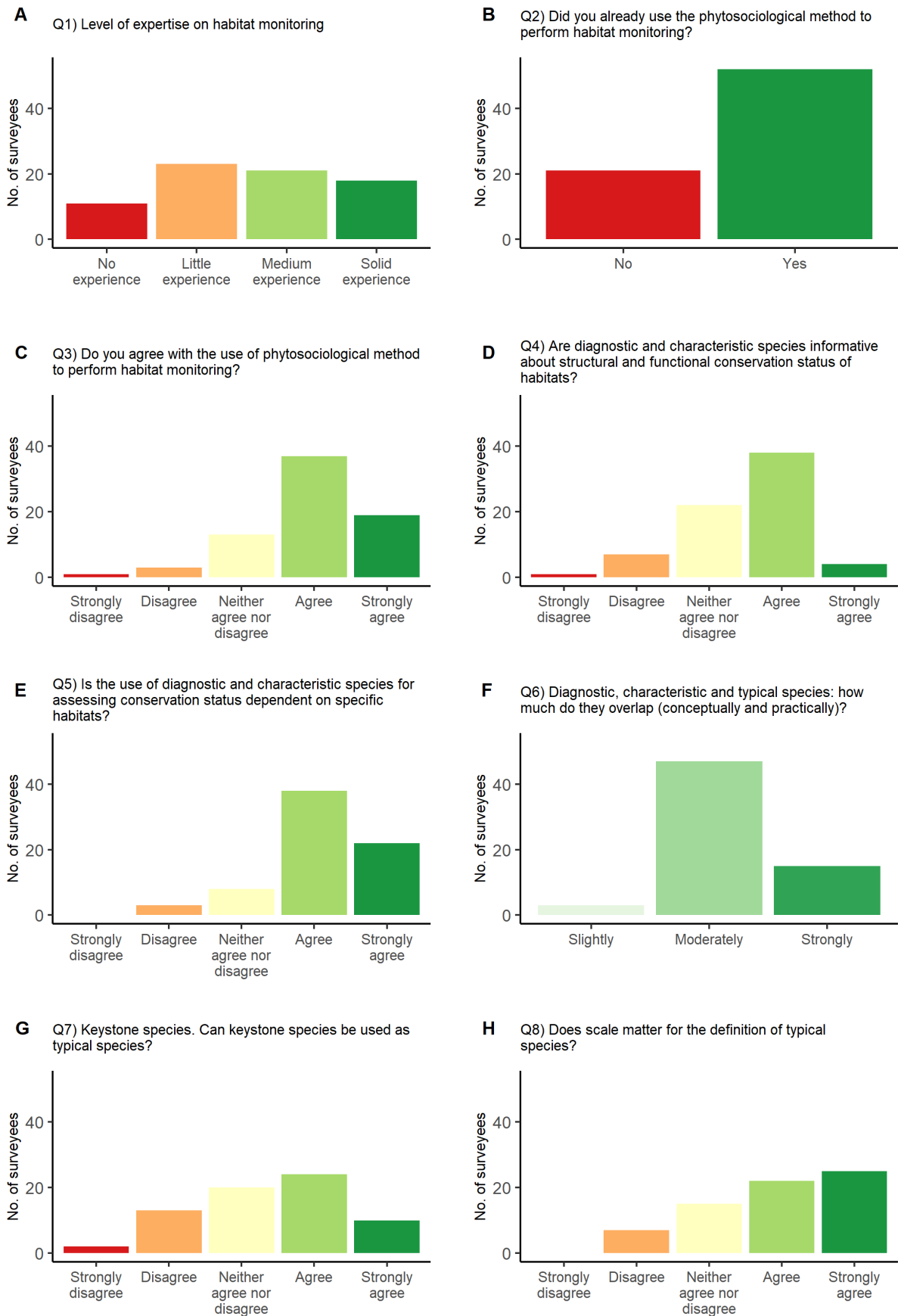


Figure 1. Barplots of the answers to the questionnaire.

neous sampling sites. A further limitation of the method highlighted during the workshop is represented by the use of the Braun-Blanquet scale (Westhoff and van der Maarel 1973; Dengler et al. 2008), which may not be sufficiently sensitive in detecting changes in species abundance over time (Londo 1976). Lastly, the phytosociological method requires specialized personnel, which restricts its applicability to specifically trained operators. To overcome these issues, many suggestions arose during the discussion. Part of them were of technical nature and can be more or less easily implemented. The use of a probabilistic sampling design, such as the stratified random sampling design, could substantially increase the objectivity of the monitoring (McGarvey et al. 2016; Corona et al. 2020; Maccherini et al. 2020), while the inclusion of other taxa and of other survey approaches (e.g., the dendrometric survey of forest vegetation; De Cáceres et al. 2019; Yao et al. 2019) can provide valuable information on the habitat conservation status. Nevertheless, a probabilistic sampling design might not be effective for habitats characterized by a limited distribution and/or a linear surface which could be underrepresented. The recently proposed Habitat Monitoring National Plan, which tries to find a cost-effective solution between totally random and opportunistic sampling, seems to go in the direction of an intermediate solution. Similarly, an intermediate solution

emerged during the workshop: first, localize and map the Habitat types through the phytosociological method, and then use a random sampling design to perform vegetation surveys and following monitoring. However, the use of permanent plots for biodiversity monitoring also represents a solid opportunity. As to the lack of sensitivity of the Braun-Blanquet scale, workshop participants proposed using a more detailed scale (i.e., 1-100%), which can more effectively detect habitat changes (Dengler et al. 2016). Yet, specialized personnel is indispensable, and it is necessary to entrust monitoring to adequately trained personnel.

Besides the methodological aspects, the workshop addressed substantial conceptual issues, such as selecting typical species *sensu* 92/43/EEC among the diagnostic and characteristic species. Diagnostic and characteristic species were originally defined for diagnostic purposes, i.e., for identifying and classifying syntaxa (Poldini and Sbrulino 2005). As such, it is still unclear whether they are suitable for evaluating habitat conservation status. Indeed, diagnostic and characteristic species can be considered as typical species, and thus be used for habitat monitoring purposes only when their relationship with habitat structure and functions is ascertained (Evans and Arvela 2011). Moreover, it should be recalled that diagnostic species are context-dependent (Chytrý et al. 2002).

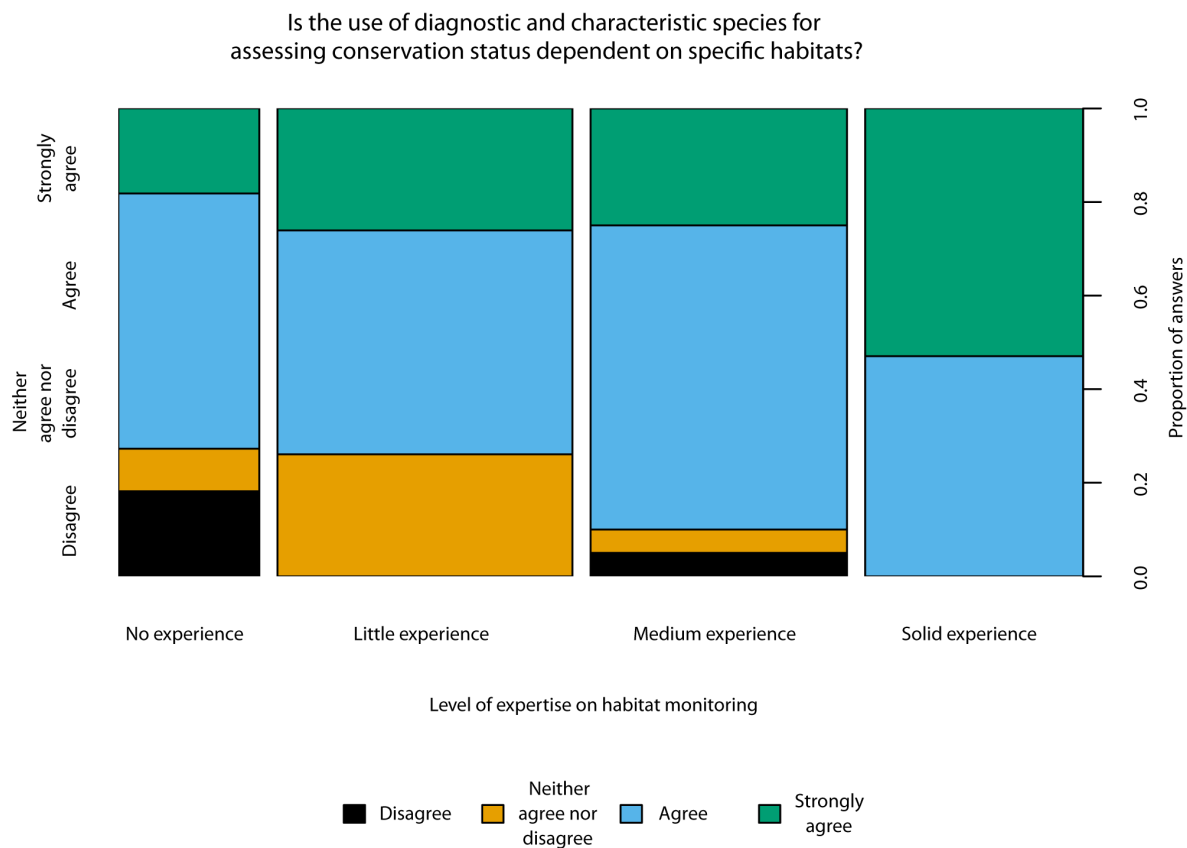


Figure 2. Spine bar plot of the ordered association between Q5, shown on y axis, and the level of experience of the surveyees. The widths of the bars correspond to the relative frequencies of surveyees for each level of expertise.

According to the mass ratio hypothesis (Grime 1998), ecosystem functioning is mainly determined by the most abundant species (and their features); therefore, the overlap between “diagnostic”, “characteristic” and “typical” species is driven by their abundance. Yet, some participants expressed their concerns about the difficulty of using diagnostic species to evaluate the conservation status of species-rich habitats, characterized by a considerable species evenness. In this context, a paradoxical question arises: how do we consider a habitat where diagnostic and characteristic species are present but typical species lack? In other words, where is the boundary between a degraded habitat in unfavourable conservation status and a shift to another habitat?

Importantly, workshop participants recalled the need of reporting, when tracking habitat conservation status, the occurrence of invasive, ruderal and in general of all those species indicating negative changes in habitat conditions (Evans and Arvela 2011). This is particularly important when dealing with invasive alien plants referred to as transformers, for their remarkable ability to deeply change the abiotic and biotic characteristics of affected ecosystems (Pyšek et al. 2004; Guarino et al. 2021), driving to a shift of structure and functions regulated by plant traits (Dalle Fratte et al. 2019), ultimately leading to the total disappearance of natural habitats. Hence, their presence, especially when still limited or even confined to nearby areas, should be carefully assessed in habitat monitoring activities. Notable examples in that regard are *Acacia* spp., *Ailanthus altissima*, *Carpobrotus* spp., and *Robinia pseudoacacia*, which have been increasingly reported in Italian Natura 2000 habitats in the last few years (Lazzaro et al. 2020). Moreover, in a recent study, Viciani et al. (2020) identified 27 vascular and one bryophyte phytosociological classes, hosting 194 low rank alien-dominated syntaxa, comprising in most cases strongly anthropogenic or highly disturbed habitats. According to these authors, regressive changes in vegetation structure and floristic composition of plant communities due to alien species invasion could be efficiently described and classified using a syntaxonomic frame (e.g., *Conyzo canadensis-Oenotheretum biennis* Biondi, Brugiapaglia, Allegranza et Ballesi 1992). Similarly, a growing bulk of data concerning aquatic habitats (e.g., macrophyte-dominated ones) show the progressive replacement of native dominant species by invasive taxa such as *Elodea* spp., *Lagarosiphon major*, *Lemna minor*, and *Nelumbo nucifera* in several lakes, rivers and wetlands across Italy (Bolpagni et al. 2017).

Another open issue regards the conceptual and factual overlap between typical and keystone species. Keystone species have a disproportionate impact on biological communities, which means that their contribution to the maintenance of an ecosystem structure and functioning is more significant than we could infer from their abundance only (Power et al. 1996; de Visser et al. 2013; Primack 2018). Although most of the participants agreed in the questionnaire on the use of keystone species as typical species, caution has been claimed during the discussion,

likely due to a lack of sufficient clarity on the concept of keystone species, and issues related to their identification. In this respect, it should be noticed that keystone species might not necessarily be plants and, given their substantial contribution to ecosystem functioning, they might not be exclusive of single habitats (Hackett et al. 2019), so that a systemic view appears increasingly critical when evaluating habitat conservation status.

During the workshop, the need for a broad perspective in habitat monitoring also emerged, especially when discussing the importance of the scale, which was deemed crucial in the definition of typical species by the majority of the surveyees. Ecosystem functioning is based on ecological mechanisms and processes mostly trespassing the borders of single habitats (Gonzalez et al. 2020). In agreement with this view, to correctly define typical species, which need to be informative of a habitat’s structure and functions, a deeper knowledge about spatial, functional and trophic interactions among neighboring habitats might be required.

Finally, it should be noted that defining a list of species that “reflect favourable structure and functions of the habitat type” (Evans and Arvela 2011) implies a thorough understanding of the structures and the functions characterizing each habitat, which might not always be available.

Conclusion

With this contribution, we attempted to shed light on the meaning and interpretation of typical species in the context of habitat monitoring. To this aim, we combined different perspectives belonging to researchers and professionals in vegetation science. In particular, most of the surveyees and participants to the workshop agreed on two issues: i) the phytosociological method is adequate for habitat monitoring and ii) diagnostic and characteristic species are informative about the structural and functional conservation status of habitats. The definition of typical species useful for habitat monitoring should be accompanied or even preceded by the parallel identification of the habitats’ structures and functions. Accomplishing these two tasks calls for a multidisciplinary approach that can be implemented only by combining different scientific knowledge and expertise. Although many open issues remain unsolved, this study represents a first attempt to provide a shared view of key concepts for habitat monitoring and conservation.

Funding

G.Bo. was funded by the Free University of Bozen-Bolzano through the CONplant project (TN201H). C.Ma. was funded by the Czech Science Foundation (Project No. 19-28491X).

Competing interests

The authors have declared that no competing interests exist.

Acknowledgments

This paper was conceived to summarize the view of the Italian Society for Vegetation Science (SISV) as the outcome of a participatory process on the topic of typical species for habitat monitoring. This contribution arises as the planned publication of the scientific workshop organized by SISV held online on 2020 October 20th entitled: “Dalla fitosociologia al monitoraggio degli Habitat (Dir. 92/43/EEC): specie caratteristiche, specie diagnostiche, specie tipiche” (From phytosociology to habitat monitoring (Dir. 92/43/EEC): characteristic, diagnostic, typical species). We thank all the participants.

Authors' contribution

G.Bo., E.F., L.L. M.G.S. joint first authorship.

S.B. conceived the idea of the workshop. S.B., G.Bo., E.F., L.L., M.G.S. conceptualization of the manuscript. A.T.R.A., M.A., S.P.A., S.B., G.Bo., M.Cac., V.D.C., E.F., A.R.F., D.G., L.L., G.R., M.G.S., G.T., B.V., D.V. organized the workshop. S.B., G.Bo., M.Cac., D.G., E.F., L.L., M.G.S. structured the workshop sessions. G.Bo., E.F., L.L., M.G.S. drafted the original manuscript, with contribution of A.T.R.A., S.B., D.G. All the co-authors commented on the manuscript.

Bibliography

- Agresti A (2002) *Categorical Data Analysis*, Second Edition. Hoboken, New Jersey: John Wiley & Sons. <https://doi.org/10.1002/0471249688>
- Angelini P, Casella L, Grignetti A, Genovesi P (2016) Manuali per il monitoraggio di specie e habitat di interesse comunitario (Direttiva 92/43/CEE) in Italia: habitat. ISPRA, Serie Manuali e linee guida, 142, 280. <http://isprambiente.gov.it>
- Balmford A (2005) The Convention on Biological Diversity's 2010 Target. *Science* 307(5707): 212–213. <https://doi.org/10.1126/science.1106281>
- Betts MG, Hadley AS, Kormann U (2019) The landscape ecology of pollution. *Landscape Ecology* 34: 961–966. <https://doi.org/10.1007/s10980-019-00845-4>
- Bland LM, Keith DA, Miller RM, Murray NJ, Rodríguez JP (2016) Guidelines for the application of IUCN Red List of ecosystems categories and criteria, Version 1.1. IUCN, Gland Switzerland. <https://doi.org/10.2305/IUCN.CH.2016.RLE.3.en>
- Biondi E (2011) Phytosociology today: Methodological and conceptual evolution. *Plant Biosystems* 145(1): 19–29. <https://doi.org/10.1080/1263504.2011.602748>

- Biondi E (2013) The 'Italian Interpretation Manual of the 92/43/EEC Directive Habitats' and the prospects for phytosociology in the field of environmental sustainability. *Archivio Geobotanico* 14(1–2): 1–16.
- Biondi E, Blasi C, Burrascano S, Casavecchia S, Copiz R, Del Vico E, et al. (2009) *Manuale Italiano di interpretazione degli habitat della Direttiva 92/43/CEE*. Società Botanica Italiana. Ministero dell'Ambiente e della tutela del territorio e del mare, D.P.N. (<http://vnr.unipg.it/habitat/>).
- Bolpagni R, Azzella MM, Agostinelli C, Beghi A, Bettoni E, Brusa G, et al. (2017) Integrating the Water Framework Directive into the Habitats Directive: Analysis of distribution patterns of lacustrine EU habitats in lakes of Lombardy (northern Italy). *Journal of Limnology* 76(s1): 75–83. <https://doi.org/10.4081/jlimnol.2017.1627>
- Braun-Blanquet J (1932) *Plant sociology. The study of plant communities*. GD Fuller and HS Conard (Eds.). Authorized English translations of 'Pflanzensoziologie'. 1st ed. Printed in the United States of America. New York and London: McGraw-Hill Book Co. Inc.
- Bunce RGH, Bogers MMB, Evans D, Jongman RHG (2013) Field identification of Habitats Directive Annex I habitats as a major European biodiversity indicator. *Ecological Indicators* 33: 105–110. <https://doi.org/10.1016/j.ecolind.2012.10.004>
- Campagnaro T, Sitzia T, Bridgewater P, Evans D, Ellis EC (2019) Half Earth or whole Earth: what can Natura 2000 teach us?. *BioScience* 69(2): 117–124. <https://doi.org/10.1093/biosci/biy153>
- Carli E, Giarrizzo E, Burrascano S, Alós M, Del Vico E, Di Marzio P, et al. (2018) Using vegetation dynamics to face the challenge of the conservation status assessment in semi-natural habitats. *Rendiconti Lincei. Scienze Fisiche e Naturali* 29: 363–374. <https://doi.org/10.1007/s12210-018-0707-6>
- Chytrý M, Exner A, Hrivnák R, Ujházy K, Valachovič M, Willner W (2002) Context-dependence of diagnostic species: A case study of the Central European spruce forests. *Folia Geobotanica* 37(4): 403–417. <https://doi.org/10.1007/BF02803255>
- Chytrý M, Tichý L, Hennekens SM, Knollová I, Janssen JAM, Rodwell JS, et al. (2020) EUNIS Habitat Classification: expert system, characteristic species combinations and distribution maps of European habitats. *Applied Vegetation Science* 23(4): 648–675. <https://doi.org/10.1111/avsc.12519>
- Corona P, Chianucci F, Marcelli A, Gianelle D, Fattorini L, Grotti M, Mattioli W (2020) Probabilistic sampling and estimation for large-scale assessment of poplar plantations in Northern Italy. *European Journal of Forest Research* 139(6): 981–988. <https://doi.org/10.1007/s10342-020-01300-9>
- Dalle Fratte M, Bolpagni R, Brusa G, Caccianiga M, Pierce S, Zanzottera M, et al. (2019) Alien plant species invade by occupying similar functional spaces to native species. *Flora* 257: 151419. <https://doi.org/10.1016/j.flora.2019.151419>
- De Cáceres M, Martín-Alcón S, González-Olabarria JR, Coll L (2019) A general method for the classification of forest stands using species composition and vertical and horizontal structure. *Annals of Forest Science* 76(2): 1–19. <https://doi.org/10.1007/s13595-019-0824-0>
- DG Environment (2017) Reporting under Article 17 of the Habitats Directive: Explanatory notes and guidelines for the period 2013–2018. Brussels. 188 pp.
- de Visser S, Thébault E, de Ruiter PC (2013) Ecosystem engineers, keystone species. In: *Ecological Systems*. Springer, New York, NY: 59–68. https://doi.org/10.1007/978-1-4419-0851-3_569

- Dengler J, Chytrý M, Ewald J (2008) Phytosociology. In: SE Jørgensen, BD Fath (Eds.), *General Ecology*. Vol. 4 of *Encyclopedia of Ecology*, 5 vols. Oxford, Elsevier: 2767–2779. <https://doi.org/10.1016/B978-008045405-4.00533-4>
- Dengler J, Boch S, Filibeck G, Chiarucci A, Dembicz I, Guarino R, et al. (2016) Assessing plant diversity and composition in grasslands across spatial scales: the standardised EDGG sampling methodology. *Eurasian Dry Grassland Group Bulletin* 32: 13–30.
- European Commission (1992) Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. *Official Journal of the European Union* 206: 7–50.
- Evans D, Arvela M (2011) Assessment and reporting under Article 17 of the Habitats Directive. *Explanatory Notes & Guidelines for the period 2007–2012*. European Commission, Brussels.
- Gigante D, Attorre F, Venanzoni R, Acosta ATR, Agrillo E, Aleffi M, et al. (2016) A methodological protocol for Annex I Habitats monitoring: the contribution of Vegetation science. *Plant Sociology* 53(2): 77–87. <https://doi.org/10.7338/pls2016532/06>
- Gigante D, Acosta ATR, Agrillo E, Armiraglio S, Assini S, Attorre F, Viciani D (2018) Habitat conservation in Italy: the state of the art in the light of the first European Red List of Terrestrial and Freshwater Habitats. *Rendiconti lincei. Scienze Fisiche e Naturali* 29(2): 251–265. <https://doi.org/10.1007/s12210-018-0688-5>
- Grime JP (1998) Benefits of plant diversity to ecosystems: immediate, filter and founder effects. *Journal of Ecology* 86(6): 902–910. <https://doi.org/10.1046/j.1365-2745.1998.00306.x>
- Gonzalez A, Germain RM, Srivastava DS, Filotas E, Dee LE, Gravel D, et al. (2020) Scaling-up biodiversity-ecosystem functioning research. *Ecology Letters* 23(4): 757–776. <https://doi.org/10.1111/ele.13456>
- Guarino R, Chytrý M, Attorre F, Landucci F, Marcenò C (2021) Alien plant invasions in Mediterranean habitats: an assessment for Sicily. *Biological Invasions*. [https://doi.org/10.1007/s10530-021-02561-0\(0123456789\(.-volV\) 0123458697\(.-volV\)](https://doi.org/10.1007/s10530-021-02561-0(0123456789(.-volV) 0123458697(.-volV))
- Guarino R, Willner W, Pignatti S, Attorre F, Loidi J (2018) Spatio-temporal variations in the application of the Braun-Blanquet approach in Europe. *Phytocoenologia* 48(2): 239–250. <https://doi.org/10.1127/phyto/2017/0181>
- Hackett TD, Sauve AMC, Davies N, Montoya D, Tylianakis JM, Memmott J (2019) Reshaping our understanding of species' roles in landscape-scale networks. *Ecology Letters* 22: 1367–1377. <https://doi.org/10.1111/ele.13292>
- IPBES (2019) Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. ES Brondizio, J Settele, S Díaz, HT Ngo (Eds.). IPBES secretariat, Bonn, Germany, 1148 pages. <https://doi.org/10.5281/zenodo.3831673>
- Jongman RHG (2013) Biodiversity observation from local to global. *Ecological Indicators* 33: 1–4. <https://doi.org/10.1016/j.ecolind.2013.03.012>
- Lazzaro L, Bolpagni R, Buffa G, Gentili R, Lonati M, Stinca A, et al. (2020) Impact of invasive alien plants on native plant communities and Natura 2000 habitats: State of the art, gap analysis and perspectives in Italy. *Journal of Environmental Management* 274: 111–140. <https://doi.org/10.1016/j.jenvman.2020.111140>
- Legg CJ, Nagy L (2006) Why most conservation monitoring is, but need not be, a waste of time. *Journal of Environmental Management* 78(2): 194–199. <https://doi.org/10.1016/j.jenvman.2005.04.016>
- Lengyel S, Déri E, Varga Z, Horváth R, Tóthmérész B, Henry P-Y, et al. (2008a) Habitat monitoring in Europe: A description of current practices. *Biodiversity and Conservation* 17(14): 3327–3339. <https://doi.org/10.1007/s10531-008-9395-3>
- Lengyel S, Kobler A, Kutnar L, Framstad E, Henry P-Y, Babij V, et al. (2008b) A review and a framework for the integration of biodiversity monitoring at the habitat level. *Biodiversity and Conservation* 17(14): 3341–3356. <https://doi.org/10.1007/s10531-008-9359-7>
- Likert R (1932) A technique for the measurement of attitudes. *Archives of Psychology* 140: 1–55.
- Londo G (1976) The decimal scale for relevés of permanent quadrats. *Vegetatio* 33(1): 61–64. <https://doi.org/10.1007/BF00055300>
- Maccherini S, Bacaro G, Tordoni E, Bertacchi A, Castagnini P, Foggi B, et al. (2020) Enough is enough? Searching for the optimal sample size to monitor European habitats: A case study from coastal sand dunes. *Diversity* 12(4): 1–16. <https://doi.org/10.3390/d12040138>
- Maciejewski L (2010) *Méthodologie d'élaboration des listes d'espèces typiques*. Rapport SPN 2010–12. Paris
- McGarvey R, Burch P, Matthews JM (2016) Precision of systematic and random sampling in clustered populations: habitat patches and aggregating organisms. *Ecological Applications* 26(1): 233–248. <https://doi.org/10.1890/14-1973>
- Oosterlynck P, Van Landuyt W, Paelinckx D (2013) Selectie habitattypische flora ten behoeve van de artikel 17 rapportage omtrent de staat van instandhouding van de Natura 2000 habitattypen. *Rapporten van het Instituut voor Natuur- en Bosonderzoek jaar (INBO.R.2013.20)*. Instituut voor Natuur- en Bosonderzoek, Brussel.
- Poldini L, Sburlino G (2005) *Terminologia fitosociologica essenziale*. *Fitosociologia* 42(1): 57–69.
- Power ME, Tilman D, Estes JA, Menge BA, Bond WJ, Mills LS, Paine RT (1996) Challenges in the quest for keystones: identifying keystone species is difficult-but essential to understanding how loss of species will affect ecosystems. *BioScience* 46(8): 609–620. <https://doi.org/10.2307/1312990>
- Primack R (2018) *Essentials of Conservation Biology*. 6th ed. Oxford University Press Inc. 601 pp.
- Proença V, Martin LJ, Pereira HM, Fernandez M, McRae L, Belnap J, et al. (2017) Global biodiversity monitoring: From data sources to Essential Biodiversity Variables. *Biological Conservation* 213: 256–263. <https://doi.org/10.1016/j.biocon.2016.07.014>
- Pyšek P, Richardson DM, Rejmánek M, Webster GL, Williamson M, Kirschner J (2004) Alien plants in checklist and floras: Towards better communication between taxonomists and ecologists. *Taxon* 53(1): 131–143. <https://doi.org/10.2307/4135498>
- Tsiripidis I, Xystrakis F, Kallimanis A, Panitsa M, Dimopoulos P (2018) A bottom-up approach for the conservation status assessment of structure and functions of habitat types. *Rendiconti Lincei. Scienze Fisiche e Naturali* 29(2): 267–282. <https://doi.org/10.1007/s12210-018-0691-x>
- Viciani D, Vidali M, Gigante D, Bolpagni R, Villani M, Acosta ATR, et al. (2020) A first checklist of the alien-dominated vegetation in Italy. *Plant Sociology* 57: 29–54. <https://doi.org/10.3897/pls2020571/04>
- Westhoff V, van der Maarel E (1973) The Braun-Blanquet approach. In: Whittaker RH (Ed.) *Handbook of vegetation science, part 5, Classification and ordination of communities*. W Junk, The Hague: 617–726. https://doi.org/10.1007/978-94-010-2701-4_20
- Yao J, Zhang C, De Cáceres M, Legendre P, Zhao X (2019) Variation in compositional and structural components of community assemblage and its determinants. *Journal of Vegetation Science* 30(2): 257–268. <https://doi.org/10.1111/jvs.12708>