

1 PLANT-ENVIRONMENT INTERACTIONS THROUGH A FUNCTIONAL TRAITS
2 PERSPECTIVE: A REVIEW OF ITALIAN STUDIES

3
4 Stefano Chelli^{1a*}, Michela Marignani^{2a}, Elena Barni^{3a}, Alessandro Petraglia⁴, Giacomo Puglielli⁵,
5 Camilla Wellstein⁶, Alicia T.R. Acosta⁷, Rossano Bolpagni⁴, Luca Bragazza⁸, Giandiego
6 Campetella¹, Alessandro Chiarucci⁹, Luisa Conti¹⁰, Juri Nascimbene⁹, Simone Orsenigo¹¹, Simon
7 Pierce¹¹, Carlo Ricotta¹², Federico M. Tardella¹, Thomas Abeli¹³, Giovanna Aronne¹⁴, Giovanni
8 Bacaro¹⁵, Simonetta Bagella¹⁶, Renato Benesperi¹⁷, Giulietta Bernareggi⁴, Giuliano Bonanomi¹⁴,
9 Alessandro Bricca⁷, Guido Brusa¹⁸, Gabriella Buffa¹⁹, Sabina Burrascano¹², Marco Caccianiga²⁰,
10 Valentina Calabrese²¹, Roberto Canullo¹, Michele Carbognani⁴, Marta Carboni²², Maria L.
11 Carranza²¹, Andrea Catorci¹, Daniela Ciccarelli²³, Sandra Citterio²⁴, Maurizio Cutini⁷, Michele Dalle
12 Fratte¹⁸, Veronica De Micco¹⁴, Silvia Del Vecchio¹⁹, Luciano Di Martino²⁵, Michele Di Musciano²⁶,
13 Edy Fantinato¹⁹, Rossella Filigheddu¹⁶, Anna Rita Frattaroli²⁶, Rodolfo Gentili²⁴, Renato Gerdol⁸,
14 Eleonora Giarrizzo¹², Paolo Giordani²⁷, Loretta Gratani¹², Guido Incerti²⁸, Michele Lussu², Stefano
15 Mazzoleni¹⁴, Andrea Mondoni¹³, Chiara Montagnani²⁴, Antonio Montagnoli²⁹, Bruno Paura³⁰,
16 Francesco Petruzzellis¹⁵, Stefania Pisanu¹⁶, Graziano Rossi¹³, Elisabetta Sgarbi³¹, Enrico Simonetti¹,
17 Consolata Siniscalco³, Antonio Slaviero¹⁹, Angela Stanisci²¹, Adriano Stinca³², Marcello Tomaselli⁴,
18 Bruno E.L. Cerabolini¹⁸

19
20 ¹ School of Biosciences and Veterinary Medicine, Plant Diversity and Ecosystems Management
21 Unit, University of Camerino, Camerino, Italy.

22 ² Department of Life and Environmental Sciences, University of Cagliari, Cagliari, Italy.

23 ³ Department of Life Sciences and Systems Biology, University of Turin, Turin, Italy.

24 ⁴ Department of Chemistry, Life Sciences and Environmental Sustainability, University of Parma,
25 Parma, Italy.

26 ⁵ Chair of Biodiversity and Nature Tourism, Estonian University of Life Sciences, Tartu, Estonia.

27 ⁶ Faculty of Science and Technology, Free University of Bozen-Bolzano, Bozen, Italy.

28 ⁷ Department of Science, University of Roma Tre, Rome, Italy.

29 ⁸ Department of Life Science and Biotechnologies, University of Ferrara, Ferrara, Italy.

30 ⁹ Department of Biological, Geological and Environmental Sciences, University of Bologna,
31 Bologna, Italy.

32 ¹⁰ Department of Botany, Faculty of Sciences, University of South Bohemia, České Budějovice,
33 Czech Republic.

34 ¹¹ Department of Agricultural and Environmental Sciences, University of Milan, Milan, Italy.

35 ¹² Department of Environmental Biology, Sapienza University of Rome, Rome, Italy.

- 36 ¹³ Department of Earth and Environmental Sciences, University of Pavia, Pavia, Italy.
- 37 ¹⁴ Department of Agricultural Sciences, University of Naples Federico II, Portici, Naples, Italy.
- 38 ¹⁵ Department of Life Sciences, University of Trieste, Trieste, Italy.
- 39 ¹⁶ Department of Chemistry and Pharmacy, University of Sassari, Sassari, Italy.
- 40 ¹⁷ Department of Biology, University of Florence, Florence, Italy.
- 41 ¹⁸ Department of Theoretical and Applied Sciences, University of Insubria, Varese, Italy.
- 42 ¹⁹ Department of Environmental Sciences, Informatics and Statistics, University Ca' Foscari of
43 Venice, Venice, Italy.
- 44 ²⁰ Department of Biosciences, Università degli Studi di Milano, Milano, Italy.
- 45 ²¹ Department of Bioscience and Territory, EnviX-Lab, University of Molise, Pesche, Isernia, Italy.
- 46 ²² Department of Biology, University of Toronto Scarborough, Toronto, Canada.
- 47 ²³ Department of Biology, University of Pisa, Pisa, Italy.
- 48 ²⁴ Department of Earth and Environmental Sciences, University of Milano-Bicocca, Milan, Italy.
- 49 ²⁵ Majella National Park, Sulmona, Italy.
- 50 ²⁶ Department of Life Health & Environmental Sciences, University of L'Aquila, L'Aquila, Italy.
- 51 ²⁷ DIFAR, University of Genova, Genova, Italy.
- 52 ²⁸ Department of Agricultural, Food, Environmental and Animal Sciences, University of Udine,
53 Udine, Italy.
- 54 ²⁹ Department of Biotechnology and Life Science, University of Insubria, Varese, Italy.
- 55 ³⁰ Department of Agriculture, Environment and Food, University of Molise, Campobasso, Italy.
- 56 ³¹ Department of Life Sciences, University of Modena & Reggio Emilia, Reggio Emilia, Italy.
- 57 ³² Department of Environmental, Biological and Pharmaceutical Sciences and Technologies,
58 University of Campania Luigi Vanvitelli, Caserta, Italy.

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60 ^a Joint first authors

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62 * Corresponding author: stefano.chelli@unicam.it, +390737404517

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71 **Abstract**

72 Italy is among the European countries with the greatest plant diversity due to both a great
73 environmental heterogeneity and a long history of man-environment interactions. Trait-based
74 approaches to ecological studies have developed greatly over recent decades worldwide, although
75 several issues concerning the relationships between plant functional traits and the environment still
76 lack sufficient empirical evaluation. In order to draw insights on the association between plant
77 functional traits and direct and indirect human and natural pressures on the environmental drivers,
78 here we summarize the existing knowledge on this topic by reviewing the results of studies
79 performed in Italy adopting a functional trait approach on vascular plants, briophytes and lichens.
80 Although we recorded trait measurements for 1418 taxa, our review highlighted some major gaps in
81 plant traits knowledge: Mediterranean ecosystems are poorly represented; traits related to
82 belowground organs are still overlooked; traits measurements for bryophytes and lichens are
83 lacking. Finally, intraspecific variation has been little studied at community level so far. We
84 conclude highlighting the need of approaches evaluating trait-environment relationship at large
85 spatial and temporal scales and the need of a more effective contribution to online databases to tie
86 more firmly Italian researchers to international scientific networks on plant traits.

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88 **Keywords:** Climate change; CSR plant strategy theory; Forest management; Intraspecific
89 variability; Land use change; Plant traits, Terrestrial and Freshwater environments.

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106 **1. INTRODUCTION**

107 Processes shaping vegetation patterns have traditionally been approached analyzing spatial and
108 temporal changes in plant species composition (McGill et al. 2006). Species identity provides
109 important information for ecological and evolutionary studies, however, this information alone does
110 not effectively contribute to the understanding of ecosystem functioning (Westoby et al. 2002;
111 Garnier et al. 2004). Considering the huge number of plant species and their uneven geographical
112 distribution, models based on species identity cannot be generalized or easily transferred to areas
113 with a different flora (Keddy 1992). Even though non-taxonomic classifications of plants have a
114 very long history (Garnier et al. 2016), the trait-based approach in ecology has substantially
115 developed over the last three decades, thanks also to the impulse of studies on global environmental
116 changes (Smith et al. 1997).

117 Plant Functional Traits are defined as "any morphological, anatomical, biochemical, physiological
118 or phenological heritable feature measurable at the individual level, from the cell to the whole-
119 organism level" (Garnier et al. 2017) that impacts plant species fitness affecting growth,
120 reproduction, resource use, establishment, etc. (Garnier and Navas 2012). Traits mediate the
121 response of plants to the environment (Lavorel and Garnier 2002), and influence ecosystem
122 functioning (Kattge et al. 2011). Accordingly, they are used in ecological research (Violle et al.
123 2007) to address fundamental questions including i) the responses of functional traits to different
124 environmental gradients at the species and community level, ii) the identification of rules governing
125 the assembly of communities, and iii) the relationships between plant functional traits and
126 ecosystem services (Garnier et al. 2016 and references therein). In spite of this, several major issues
127 in trait-based ecology still lack sufficient empirical evaluation (Shipley et al. 2016).

128 Italy is the European country with the highest number of native vascular plant species and
129 subspecies (Bartolucci et al. 2018); at the same time it has a long history of human pressures on the
130 environment that still influences a wide range of ecosystems. Such a high plant diversity derives
131 from a wide latitudinal gradient and from the remarkable heterogeneity in terms of climate and
132 physiography, along with a complex biogeographic evolution (Smiraglia et al. 2013; Blasi et al.
133 2014). These conditions allow for a broad variety of natural vegetation types (Blasi et al. 2010) that
134 is enriched by the occurrence of semi-natural ones, deriving from the long history of human
135 activities (Capotorti et al. 2012). In parallel, global changes are shaping biodiversity and ecosystem
136 functioning in Italy with different patterns and rates across the various environments (Chelli et al.
137 2017). For instance, due to the ongoing climate change, Italy results one of the European countries
138 most prone to extreme drought (Spinoni et al. 2018) and temperature increase (Rogora et al. 2018).
139 Its forests were subjected to timber exploitation since the Roman times (Vacchiano et al. 2017), and
140 it is now undergoing land-use change at very high rate with a consistent process of reforestation and

141 a steady decrease of pasture extent (Falcucci et al. 2007; Malavasi et al. 2018). Furthermore, its
142 sandy shorelines have been heavily transformed in the last 60 years with considerable loss or
143 modification of natural vegetation (Malavasi et al. 2013). For these reasons, the analysis of
144 environmental and human-related gradients, as well as the mechanisms through which these
145 gradients shape community composition and determine specific ecosystem services is particularly
146 challenging in Italy. In this view, Italy may serve as a model region to test the effectiveness of trait-
147 based approaches.

148 In order to draw general insights on the association between plant functional traits and direct and
149 indirect natural and human pressures on environmental drivers, here we summarize the existing
150 knowledge on this topic by reviewing the results of Italian studies that used the functional traits of
151 vascular plants, bryophytes and lichens.

152 Especially, we aim to: (1) assess the 'state of the art' of the relation between plant traits and both
153 environmental or human drivers in Italy, (2) identify the most frequently investigated research
154 fields, above all those dealing with global change drivers, summarizing major results, in order to
155 contribute to their empirical evaluation and (3) identify knowledge gaps and suggest operative
156 indications for the Italian research community to fill them.

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158 **2. MATERIALS AND METHODS**

159 We collected 164 papers during a workshop of the Italian Botanical Society specifically organized
160 for this purpose (Plant traits 2.0: State of the art and future perspectives for research on plant
161 functional traits in Italy, February 9-10, 2017, Bologna, Italy). In addition to this event we carried
162 out a literature search through ISI® Web of Science and Google Scholar as well as through cross-
163 referencing. The search terms for the query (October 11th, 2017) were "plant functional trait*" AND
164 "Italy". In the Web of Science, a total of 83 references were found; among them, 40 were already
165 included, 23 were not relevant for the review, and the remaining 20 papers were added to our
166 database. In Google Scholar only the first 300 items (ranked by relevance) were checked, and 4
167 additional studies matching the requested criteria were found.

168 In general, studies were included if meeting the following criteria: i) performed in Italy, ii)
169 published in peer-reviewed journals, iii) focused on the relationship of response and/or effect traits
170 (sensu Lavorel and Garnier 2002) of vascular plants, bryophytes and lichens to environmental
171 variables/gradients. The review has a broad focus on the plant functional traits approach, it includes
172 studies based on both field/greenhouse measurements of traits according to standard methods and
173 on traits collected from databases aimed at gaining deeper insights into ecological functioning at
174 species and community levels in terrestrial and freshwater environments. We excluded studies
175 related to marine environments, crops, and those based on modelling, pollen analysis,

176 bioaccumulation, phytoremediation, and dendroecology.
177 Altogether, 188 articles were identified and included in the review (Appendix 1). The following
178 main topics were recognized: (a) impact of climate change on functional traits; (b) response of
179 functional traits to forest management and eutrophication; (c) secondary grasslands, grazing and
180 land-use change; (d) CSR plant strategy theory; (e) Plant functional traits and ecological processes
181 in coastal ecosystems; (f) Plant functional traits and intraspecific variability; (g) aquatic
182 environments and plant growth: evidence from river and shallow inland ecosystems.

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184 **3. RESULTS AND DISCUSSION**

185 Similarly to the temporal trend of the international scientific production on plant functional traits
186 (source: ISI® Web of Science, search terms "plant functional trait*"), the vast majority of Italian
187 studies using the functional approach were performed during the last decade (Fig. 1a). Studies were
188 mainly carried out in the Continental biogeographic region (sensu Roekaerts 2002; 42%), while a
189 lower number of papers referred to the Alpine (32%) and the Mediterranean region (26%), despite
190 the fact that the latter comprises more than 50% of the Italian territory. Semi-natural grasslands and
191 forests (24 and 23%, respectively) were the most studied ecosystems, while only few studies have
192 dealt with Mediterranean shrublands and agroforestry systems (3%), and alpine/sub-alpine
193 peatlands (5%, Fig. 1b).

194 For vascular plants, we discuss traits belonging to the following categories: whole-plant traits
195 (Kleyer et al. 2008; Pérez-Harguindeguy et al. 2013), leaf traits (Pérez-Harguindeguy et al. 2013;
196 Garnier et al. 2017), seed and dispersal traits (or regenerative traits, sensu Pérez-Harguindeguy et al.
197 2013), phenology and flowering traits (Kühn et al. 2004), clonal traits (Klimešová et al. 2017), root
198 traits (or belowground traits, sensu Pérez-Harguindeguy et al. 2013; Garnier et al. 2017). Among
199 these, leaf (28%) and whole-plant traits (27%) were used with a similar relatively high frequency.
200 Phenological, seed and clonal traits were also well represented (17%, 12% and 9%, respectively),
201 while few papers dealt with root traits (2%). Canopy height, specific leaf area (SLA), flowering
202 phenology, seed mass, leaf dry matter content (LDMC), leaf nitrogen, and vegetative propagation
203 were the most frequently used PFTs (at least in 20 papers). These are commonly recognized as key
204 traits related to fundamental plant challenges (dispersal, establishment, persistence; Weiher et al.
205 1999) and are inherent to major ecological strategy theories, such as (i) the Leaf-Height-Seed plant
206 ecology strategy scheme (including SLA, canopy height and seed mass; Westoby et al. 1998), (ii)
207 the CSR strategy scheme (SLA, LDMC; Grime and Pierce 2012; Pierce et al. 2013), and (iii) the
208 Leaf Economics Spectrum (Wright et al. 2004).

209 For bryophytes, we selected the following categories according to Cornelissen et al. (2007): tissue
210 chemistry traits, carbon gain related traits, traits related to carbon and nutrient losses (litter

211 chemistry), other morphological and cytological traits. The most represented were tissue chemistry
212 traits and traits related to carbon and nutrient loss, but only in studies conducted in the alpine
213 biogeographic region.

214 All functional traits considered were primarily measured from specimens collected in the field. In
215 detail, traits were measured for 1080 vascular plants and 15 bryophyte species (Appendix 2).
216 Flowering phenology was the functional trait more frequently measured on vascular plant species
217 (>800 species), followed by canopy height and SLA (>700 species; Fig. 1c). In contrast, functional
218 traits of lichens were obtained mainly from databases (i.e. *Italic 5.0*; Nimis and Martellos 2017).

219 In Italy, plant functional traits have been used to answer many ecological questions (Table 1): many
220 traits have been used in studies dealing with forest management, grazing and land-use change, but
221 with discrepancies among biogeographic regions (Table 1); while, for instance, few traits were used
222 in invasiveness studies, along successions or in relation to ecosystem functions. Additionally, clonal
223 and root traits were never considered in studies on climate change.

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225 **3.1. Impact of climate change on functional traits**

226 Studies were conducted through manipulation experiments or observational approaches.
227 Experiments dealing with seed traits were performed exposing parental alpine plants or dispersed
228 seeds to warming. Seeds produced by plants exposed to moderate warming (+1.5°C) were more
229 resistant to heat (Bernareggi et al. 2015) and showed changed germination/dormancy responses
230 with respect to controls, with deeper and less dormant seeds showing major changes in response to
231 incubation temperatures and to cold stratification periods, respectively (Bernareggi et al. 2016).
232 Alpine plant seeds directly exposed to warming after dispersal showed a general increase in
233 germination rate both in spring and autumn, with a subsequent high percentage of seedling survival
234 in winter (Mondoni et al. 2012, 2015; Orsenigo et al. 2015). The exposition of seeds of two
235 Mediterranean annual species to water stress led to reduced and delayed germination with
236 contrasting responses among populations, revealing a possible adaptation to drought stress in the
237 southernmost population (Orsenigo et al. 2017).

238 Experiments focused on flowering time revealed a plastic response to changing micro-climatic
239 conditions, both for snowbed-specialized and alpine generalist species (Petraglia et al. 2014b,
240 Carbognani et al. 2016). Petraglia et al. (2014b) showed that for many species, flowering time was
241 tuned by snowmelt date and temperature. However, Carbognani et al. (2016) highlighted the
242 importance of timescale of the observations, with snowmelt time playing a major role at annual
243 scale and temperature at the growing season timescale. Even observational approaches studying
244 flowering of primary grasslands species in N-Apennines showed a plastic response of different
245 species. In general, inflorescence production was affected by mean summer temperature, suggesting

246 a change in reproductive strategies (e.g. changes in the ratio sexual/clonal reproduction, Abeli et al.
247 2012a). However, also snow cover persistence was a relevant driver of the reproductive effort in
248 some species, with a significant decrease of inflorescence production with reduced snow cover
249 persistence both in primary grasslands (Abeli et al. 2012b) and dwarf-shrub heath (Gerdol et al.
250 2013a).

251 The response of leaf traits to experimental extreme drought was studied in sub-Mediterranean
252 secondary grasslands (Wellstein et al. 2017) and resulted in differential patterns (through
253 phenotypic adjustment) of functional groups: grasses increased significantly their SLA under
254 drought, indicating better growth performance of these species, which is most likely related to their
255 strategy to allocate resources to belowground parts. In contrast, forbs showed a SLA reduction as a
256 response to water stress.

257 Regarding the analysis of plant traits turnover through long-term observations, significant floristic
258 and functional changes occurred over the last 42 years in alpine and subalpine grasslands of central
259 Apennines, with an increase in thermophilous, nitrophilous and mesophilous plant species and an
260 increment in the frequency of hemicryptophytes (Evangelista et al. 2016). These changes are likely
261 attributable to the combined effect of higher temperatures and the increase in soil nutrients triggered
262 by global change. A thermophilization trend has been also documented in several European
263 mountains and have been related mainly to the effects of climate change (e.g. Britton et al. 2009;
264 Engler et al. 2011; Gottfried et al. 2012; Frate et al. 2018). Accordingly, recent evidence (e.g.,
265 Spasojevic et al. 2013) suggests that variations in nutrient availability, soil moisture and
266 temperature led to changes in the functional composition of alpine plant communities with a shift
267 towards more resource acquisitive functional traits (e.g., hemicryptophytes with well-developed
268 leaves).

269 Among the papers dealing with lichens, photobiont type, thallus growth forms and dispersal
270 strategy were the most studied functional traits, at national (Marini et al. 2011; Giordani et al. 2012)
271 or local level, spanning from glacier forelands to Mediterranean systems (Favero-Longo et al. 2014;
272 Nascimbene and Marini 2015; Nascimbene et al. 2017; Giordani et al. 2014c). Thallus growth form
273 and photobiont type were responsive to climate factors in several ecosystems both at national
274 (Marini et al. 2011; Giordani et al. 2012) and local level (Nascimbene and Marini 2015;
275 Nascimbene et al. 2017), representing a promising tool for detecting the effects of climate change
276 on lichen species. For instance, thallus growth forms showed contrasting patterns related to
277 temperature in forest ecosystems, with crustose species being enhanced by warming, and fruticose
278 and foliose lichens being negatively impacted by warming (Nascimbene and Marini 2015). Also
279 photobiont type (i.e. the photosynthetic partner of the lichen symbiosis) showed differential
280 response to climate variables: despite the general dependence of lichens on water supply, lichens

281 characterized by Trentepohlia algae were further enhanced by warming, while species richness of
282 lichens characterized by cyanobacteria was only related to precipitation (Marini et al. 2011).

284 **3.2. Response of functional traits to forest management and eutrophication**

285 Understory species compositional changes during the regeneration phases after coppicing appeared
286 to be driven by plant functional traits, in particular leaf, clonal and reproductive traits (Canullo et al.
287 2011, 2017; Campetella et al. 2011; Catorci et al. 2012a). In detail, changes in environmental
288 conditions during the forest regeneration after coppicing filtered species with high SLA values
289 (Campetella et al. 2011; Catorci et al. 2012a), short-distance dispersal (Campetella et al. 2011),
290 early leaf and flower production (Catorci et al. 2012a) and high mobility due to stem-derived clonal
291 growth organs (i.e. hypogeogenous rhizomes; Canullo et al. 2011, 2017). Additionally, understory
292 traits composition was influenced by the presence of the alien trees *Prunus serotina* and *Robinia*
293 *pseudoacacia* but with different impact, suggesting the importance of different management and
294 control strategies (Terwei et al. 2016).

295 Papers comparing different types of forest management, namely old coppice vs high forest, showed
296 contrasting results: the understory herbaceous layer did not show significant differences in leaf,
297 flowering, whole-plant and seed attributes (Scolastri et al. 2017); in contrast, belowground traits
298 (i.e. fine-root traits) of tree species (*Fagus sylvatica*) were sensitive to management. In particular,
299 fine-root standing biomass decreased and Nitrogen concentration increased with the reduction of the
300 stand density. Furthermore, both fine-root production and turnover rate were lower, and C:N ratio
301 higher, in dense old coppice than in thinned high forest stands (Montagnoli et al. 2012a; Terzaghi et
302 al. 2013), suggesting the importance to explore belowground traits in future studies. In absence of
303 management, local ecological continuity favoured species with low dispersal ability (i.e. large seeds
304 with low persistence in the soil, and short-distance animal dispersion; Ricotta & Burrascano 2008;
305 Burrascano et al. 2009). However, despite differences in terms of functional traits between
306 unmanaged and managed forests, the difference in their functional beta diversity values are only
307 marginally significant, probably due to the different spatial scale at which ecological variations
308 occur in forest stands with different management histories (Ricotta & Burrascano 2008).

309 For lichens, three functional traits were mainly considered, namely photobiont type, thallus growth
310 forms and dispersal strategy. Lichens were sensitive to forest management (Nascimbene et al. 2007;
311 Nascimbene et al. 2008). In particular, the release of deadwood in managed forests was a key factor
312 for the maintainance of lichens functional diversity. The occurrence of deadwood in different decay
313 status supported a broad lichen community (Nascimbene et al. 2008). Lichen growth form was the
314 most responsive trait and was considered a reliable indicator for evaluating and comparing the
315 responses of epiphytic lichens to atmospheric deposition in forests across diverse regions (Giordani

316 et al. 2012; Giordani et al. 2014). In particular, Giordani et al. (2014) showed that the percentage of
317 macrolichens was the most reliable indicator, since 56.7% of its variation could be explained by
318 nitrogen deposition. Moreover, both narrowly lobed and broadly lobed foliose lichens were
319 negatively affected by acidic deposition, while narrowly lobed species were also negatively
320 influenced by increasing concentrations of SO_4^{2-} (Giordani et al. 2012). Under high eutrophication
321 levels, differences in tree-related factors were not related to significant differences in epiphytic
322 lichen communities composition (Giordani & Malaspina 2016). In fact, different epiphytic lichen
323 functional groups with different nitrogen tolerances responded to several atmospheric pollutants,
324 which had both independent and joint effects, whereas they did not show significant differences
325 depending on bark pH.

326

327 **3.3. Secondary grasslands, grazing and land-use change**

328 Changes in grazing intensity produced significant changes in species and functional traits
329 composition in montane grasslands (Catorci et al. 2016; Giarrizzo et al. 2017). The increase in
330 grazing pressure produced an increase in species showing traits associated with frequent disturbance
331 (Giarrizzo et al. 2017), usually poorly palatable and characterized by strong grazing avoidance
332 strategies (Catorci et al. 2016). In lichens, Giordani et al. (2014a) found a similar shift, with a
333 significant increase in the similarity of the oligotrophic component of lichen communities due to
334 nitrogen accumulation. Grazing cessation leads to an overall reduction of functional diversity
335 together with an increase in productivity through a shift from functional strategies devoted to
336 grazing avoidance and tolerance to those devoted to competition for light and resource acquisition
337 (Tardella & Catorci 2015). In fact, in abandoned grasslands several studies assessed how the
338 dominance of some grasses (e.g. *Brachypodium genuense*, Tardella et al. 2017; *Sesleria nitida*,
339 Wellstein et al. 2014) influence community composition by competitive exclusion of subordinate
340 species. Such dominance proved to be context-dependent and related to functional traits. For
341 instance, in central Apennines, *Brachypodium genuense* populations showed different strategies
342 under different conditions (mesic vs xeric), with a fast-growing strategy and high competitive
343 ability (high SLA and plant height) in productive environments (Tardella et al. 2017). Even
344 subordinate species, which often are highly palatable for wild herbivores (Corazza et al. 2016),
345 showed different context-dependent trait-based strategies to coexist and to cope with the dominant
346 species. Here, flowering, whole plant, seed, clonal and belowground traits played a key role
347 (Halassy et al. 2005; Catorci et al. 2012b; Wellstein et al. 2014; Corazza et al. 2016). However, the
348 impact of grazing on functional composition of grasslands may vary with climate, productivity,
349 dominant life forms and may not be functionally related to direct herbivore damage (McIntyre et al.
350 1999, and references therein).

351

352 **3.4. CSR plant strategy theory**

353 Competitor, stress-tolerator, ruderal (CSR) plant strategy theory was conceived by Grime (1974,
354 1977, 2001) as a trade-off between three extreme adaptive trait syndromes that have evolved in
355 response to competition (biotic limitations to biomass production), stress (abiotic limitations to
356 productivity) and disturbance (biomass destruction). In Grime's most modern definition (Grime &
357 Pierce 2012) these trait syndromes are supposed to facilitate the survival of genes via: "(C) the
358 survival of the individual using traits that maximise resource acquisition and resource control in
359 consistently productive niches, (S) individual survival via maintenance of metabolic performance in
360 variable and unproductive niches, or (R) rapid gene propagation via rapid completion of the
361 lifecycle and regeneration in niches where events are frequently lethal to the individual". This
362 formulation has the advantage of being the only trait-based ecological strategy theory with
363 empirical support across major taxonomic groups (Grime & Pierce 2012).

364 In terms of traits, the fundamental characters that can universally link CSR strategies in all
365 organisms are the proportions of essential elements (especially carbon, nitrogen and phosphorus)
366 "invested in traits involved in resource acquisition, maintenance or regeneration". Thus, the
367 quantity of biomass produced is related to the amount of carbon acquired by the organism, and
368 tissue density to the way in which essential elements are deployed for primary metabolism or
369 reproduction. In a practical sense, plant traits that are measured include size traits such as leaf area
370 or canopy height, resource-use and tissue density traits such as SLA and LDMC, respectively, or
371 reproductive traits, particularly those involved in flowering and fruiting phenology (Hodgson et al.
372 1999; Pierce et al. 2013, 2017). These trait relationships have been confirmed to reflect fundamental
373 underlying trade-offs throughout vascular plants (Díaz et al. 2016). Crucially, it is important to
374 avoid the misconception that each trait is measured to represent either C, S, or R: CSR values
375 represent the balance between traits and thus the three-way trade-off. For example, the degree of
376 'C-selection' is never calculated from a single trait, but is weighted by all of the traits measured
377 (Pierce et al. 2017).

378 The CSR approach proved to be suitable outside its original area of development (Britain), and to
379 be consistent with traits variation in a broad sample of Italian species (including aquatic plants,
380 Pierce et al. 2012) of the continental, sub-alpine and alpine bioclimatic zones (Cerabolini et al.
381 2010b), but also in coastal habitats (Ciccarelli 2015). Specifically, high elevation species were
382 predominantly stress-tolerators but included some competitive-ruderals and ruderals (Fig. 2a;
383 Caccianiga et al. 2006; Pierce et al. 2007a,b; Gentili et al. 2013). Here, both abiotic stress resulting
384 from a scarcity of resources and physical disturbance limited plant growth. Several studies
385 conducted along transects in glacier forelands demonstrated a functional shift from broadly ruderal

386 pioneers towards stress tolerance in late succession (Caccianiga et al. 2006; Gobbi et al. 2010). This
387 shift was also reflected in phylogenetic changes, indicating that species sorting by environmental
388 filtering tends to favor the co-occurrence of phylogenetically related species (Ricotta et al. 2015).
389 Additionally, the progressive substitution of ruderal species by stress tolerators was accompanied by
390 a constant and significant decrease in community-level functional diversity and uniqueness,
391 meaning that the increased uniformity of vegetation structure over time goes together with an
392 increase in functional redundancy (Ricotta et al. 2016). Till deposited at the retreating glacier
393 terminus provides a substrate that can support faster growing species (with high foliar N contents),
394 but is only tenable to those that can avoid physical disturbance via rapid phenological development
395 (i.e. ruderals), while stress-tolerance (and lower N contents) in late succession suggested selection
396 for efficient nutrient use (Caccianiga et al. 2006; Gobbi et al. 2010). Interestingly, such functional
397 shifts (from R-strategists to S-strategist) have been confirmed also in coastal dune primary
398 successions (Ciccarelli 2015), suggesting that during primary successions there is a shift from
399 ruderality to stress-tolerance across ecosystems (Fig. 2b).

400 In sub-alpine secondary grasslands, the most abundant species were stress-tolerators, ruderals and
401 competitive-ruderals, demonstrating the existence of contrasting opportunities for survival, based on
402 nutrient availability and grazing pressure (Fig. 2c; Pierce et al. 2007a; Cerabolini et al. 2010a). In
403 contrast, in lowland grasslands, species were predominantly competitive-ruderals but included some
404 stress-tolerators (Pierce et al. 2007b). However, the number of strategies strongly depended on
405 biomass production, with the higher values (also in terms of species richness and trait variance)
406 occurring at intermediate biomass, while extremes of biomass production were associated with
407 relatively few taxa exhibiting similar trait values and specialised strategies (Cerabolini et al. 2016).
408

409 **3.5. Plant functional traits and ecological processes in coastal ecosystems**

410 Plant functional traits gave useful insights into the temporal trends and into the conservation status
411 of sandy coastal systems. Prisco et al. (2016) showed that a general increase in natural vegetation
412 cover occurred in recent years in coastal protected areas, although this increase was mainly in the
413 wooded dune habitats. Here, late-successional, tall-growing and large-seeded species showed the
414 clearest signs of cover expansion. However, this expansion occurred in part at the expense of
415 coastal dune grasslands, which thrive under the natural disturbance regimes of healthy coastal dune
416 systems, and have declined since the 1960s. In fact, the total cover of therophytes and species with
417 high LDMC values has tended to decrease (Prisco et al. 2016). Then, by analyzing temporal trends
418 in functional traits, Prisco et al. (2016) were able to determine which type of species were favoured
419 and which were not, and why. Similarly, the functional approach was better than focusing solely on
420 taxonomic diversity, for capturing the response of plant communities to spatial and temporal

421 landscape patterns in coastal sand dunes. In fact, while taxonomic diversity seemed to be only
422 moderately affected by landscape processes, this was not the case for functional diversity (Malavasi
423 et al. 2016). In addition, Jucker et al. (2013) also found a negative association of both the
424 taxonomical and the functional diversity of coastal dune communities with the level of invasion by
425 a highly invasive alien species from South Africa (*Carpobrotus* spp.). By examining trait patterns,
426 the authors hypothesized that this is likely the result of the selective exclusion of specific functional
427 groups from the native community by this highly competitive alien plant, through a combination of
428 niche- and fitness-related processes. Moreover, Stanisci et al. (2010) using a functional approach
429 including belowground traits, pinpointed the characteristics of the most successful invaders among
430 alien taxa in coastal sand dunes: large leaf area, biennial/annual life cycle and thick and long roots.
431 Plant functional traits have also been useful to infer assembly rules in plant communities
432 particularly along natural stress gradients, which have been extensively studied in coastal sand
433 dunes. Specifically, by allowing the quantification of species' ecological niches, functional traits can
434 be used to test the predominance of certain ecological filters along gradients, thereby allowing to
435 make inferences on the processes behind the co-existence of species under different levels of abiotic
436 stress. For example, coastal habitats closer to the sea (higher levels of environmental stress) were
437 found to have higher proportions of specialized species. On the contrary, sheltered backdune
438 habitats, at the other end of the gradient, were mostly dominated by generalists (Carboni et al.
439 2016). Recently, Conti et al. (2017) suggested that in order to assess the assembly processes
440 underlying community patterns, it is revealing to analyze jointly the functional and the spatial
441 patterns of species co-occurrences, as they can convey complementary information, while also
442 accounting for the so-far overlooked role of micro-environmental heterogeneity. For example, in
443 Central Italian coastal dunes, spatial segregation of species within communities was more common
444 farther from the sea, suggesting the dominance of competitive processes in the least stressed
445 communities. But in addition, whether the species coexisting within communities shared similar or
446 highly divergent functional traits (i.e. plant height, seed mass, SLA), depended not only on the
447 average stress level along the gradient, but also on the environmental heterogeneity within the
448 community. Finally, functional patterns in coastal plant communities were also partly linked to
449 phylogeny. At the overall species pool level, there was evidence of a phylogenetic signal in species
450 traits (i.e. closely related species shared similar traits). However, while functional diversity among
451 communities was closely mirrored by their phylogenetic variability, this was not the case for the
452 communities' functional composition (Carboni et al. 2013). In conclusion, functional trait patterns
453 have been shown to be useful to gain insights into the processes of both plant community assembly
454 and invasion in coastal dune systems.

455

456 3.6. Plant functional traits and intraspecific variability

457 Most of the studies included species of montane primary and secondary grasslands (Wellstein et al.
458 2013; Catorci et al. 2014c; Gratani et al. 2012, 2014; Puglielli et al. 2015a), with *Sesleria nitida*
459 (Wellstein et al. 2013; Gratani et al. 2014; Puglielli et al. 2015a), an endemic grass of the montane
460 belt of the Apennines, being the most represented. Such species showed significant intraspecific
461 differences in trait attributes. In detail, leaf traits (mainly SLA or its inverse LMA, leaf tissue
462 density, LTD, and leaf thickness, LT) of *S. nitida* were highly responsive to light availability
463 (Puglielli et al. 2015a) and elevation (as proxy of temperature, Gratani et al. 2014), with mean
464 plasticity index (PI, *sensu* Valladares et al. 2000) ranging from 0.05 to 0.32 (for SLA plasticity see
465 Fig. 3). However, Wellstein et al. (2013) showed a relatively low plasticity of leaf traits and plant
466 height in two contrasting grasslands (mesic vs xeric), while clonal traits demonstrated to be highly
467 plastic. The investigated clonal traits were related to space occupancy and multiplication frequency
468 and were regulated by soil nutrient and moisture availability.

469 Different studies focused on species of Mediterranean ecosystems using field observations
470 (Crescente et al. 2002; Puglielli et al. 2017a; Gratani et al. 2018) and common garden approaches
471 (Gratani et al. 2003; Catoni and Gratani 2013; Puglielli et al. 2017b). In particular, Crescente et al.
472 (2002), Gratani et al. (2003) and Peguero-Pina et al. (2017) revealed significant levels of
473 phenotypic plasticity for plant and leaf traits in *Quercus ilex* ecotypes. For example, PI for plant
474 height was 0.50 for *Q. ilex* individuals growing at a climax area and at the northern distribution
475 limit of the species in Italy (Crescente et al. 2002). At the leaf level, PI values for SLA and LTD
476 ranged between 0.15-0.27 and 0.15-0.32, respectively, in *Q. ilex* plants grown from acorns sampled
477 along an aridity gradient (Gratani et al. 2003). A remarkable leaf morphological plasticity of SLA
478 and LT was also found in the widespread Mediterranean shrub *Cistus salvifolius* in response to a
479 reduced light environment (Puglielli et al. 2017a). Moreover, SLA changes were also mostly related
480 to changes in physiological and biochemical leaf traits revealing a long-term acclimation process of
481 *C. salvifolius* to a low light environment. Also, within species inter-annual variability in anatomical
482 components of LMA has been demonstrated to reduce net photosynthesis (on area basis)
483 responsiveness to air temperature changes (Gratani et al. 2018). However, such relationship held
484 only for evergreen sclerophyllous species compared to semi-deciduous ones, highlighting that inter-
485 annual leaf plasticity patterns in response to temperature (and their relationship with
486 photosynthesis) depend on leaf habitus within Mediterranean communities. At the within individual
487 level, Puglielli et al. (2017b) demonstrated that different leaf cohorts of *Cistus* spp. are
488 characterized by differences in leaf trait coordination patterns. Such strategy allows species to
489 modulate resource-acquisition and -use strategies with varying environmental conditions,
490 highlighting another level of phenotypic plasticity. Relevant levels of phenotypic plasticity in

491 leaf traits have been found also in *Fagus sylvatica*, *Picea excelsa* and *Populus nigra* along
492 biogeographical gradients in studies conducted at continental scale, including also Italy (Bauer et al.
493 1997; Kang et al. 2011; Guet et al. 2015).

494 The increased interest payed to the inclusion of intraspecific variability in ecological studies raised
495 also the question whether different spatial levels could account for different proportion of traits'
496 variability. As an example, Petruzzellis et al. (2017) compared variability patterns across multiple
497 spatial scale of one morphological (SLA) and one physiological (leaf osmotic potential, π)
498 functional trait in a population of *Q. ilex*. They found that the variability of SLA was mainly spread
499 within individuals, while the variability of π was much higher between rather than within
500 individuals of the same species. This difference opens interesting questions about the patterns of
501 intraspecific trait variability in different species, encouraging future analyses including more traits
502 and more species.

503

504 **3.7. Aquatic environments and plant growth: evidence from river and shallow inland** 505 **ecosystems**

506 River stretches, wetlands and eutrophic shallow lakes of the continental biogeographic region in
507 northern Italy were the most studied environments. Several papers were focused on single species.
508 Studies related to growth form and performance of *Phragmites australis* found significant
509 differences in attributes according to site-specific ecological status. Flooded stands or sites with
510 permanent submersion were characterized by high rates of clumping habit and dead apical bud, and
511 lower culm diameters, showing clear signs of plants dieback (Lastrucci et al. 2016, 2017). Other
512 studies addressed the growth response of a rare fern, *Marsilea quadrifolia*, and a widespread
513 opportunistic species, *Vallisneria spiralis*, respectively to sediment trophic level and physico-
514 chemical water features, demonstrating a certain capacity of both species to grow under varying
515 levels of nutrients in water and sediment (Bolpagni & Pino 2017; Bolpagni et al. 2015). Finally, two
516 studies focusing on plant-mediated gas exchange of *Trapa natans* clarified its pivotal role in
517 inducing persistent hypoxia and anoxia in the colonized water bodies, and in conditioning CO₂ and
518 CH₄ stand fluxes at the water-atmosphere interface (Bolpagni et al. 2007; Pierobon et al. 2010).

519 At community level, Oglio river wetlands (Northern Italy) were studied in order to assess the effect
520 of wetland origin (natural vs artificial) and hydrology (lotic vs lentic) in shaping growth forms
521 composition of riverine wetland vegetation. In general, data revealed the predominance of terrestrial
522 herbaceous species and the deterioration of the obligate aquatic plant contingent and the helophyte
523 representativeness in such ecosystems (Bolpagni et al. 2013; Bolpagni & Piotti 2015, 2016).
524 Wetlands origin and their structural complexity rather than hydrological features seemed to
525 condition community composition in terms of growth forms (Bolpagni et al. 2013; Bolpagni &

526 Piotti 2016).

527 Furthermore, some studies coupled the remote sensing approaches with field sampling to appreciate
528 macrophyte's growth forms distribution at different spatial scales along time or water feature
529 gradients in lakes (Bolpagni et al. 2014; Villa et al. 2015, 2017). This constitutes a step forward for
530 macrophyte's traits mapping going beyond the local scale, and can be used for supporting regional
531 to continental monitoring of spatial and temporal dynamics of primary producers in freshwater
532 ecosystems (Villa et al. 2015, 2017).

533 Only one study was related to lichens (Nascimbene et al. 2009), evaluating the effectiveness and
534 life-strategies of freshwater lichens in colonizing newly constructed stone structures in low-
535 elevation streams. Size of thalli, morphological and ontogenetic traits of the species were influenced
536 by the age of restored habitats.

537

538 **4. CONCLUSIONS AND FUTURE RESEARCH PERSPECTIVES**

539 Our review represents the first comprehensive overview of the main findings in studies linking plant
540 functional traits to environmental and human drivers in Italy. It can be a step stone to develop
541 functional quantitative analyses of plant communities based on plant traits, especially in Ecosystem
542 Services evaluations, and it can be a starting point to extend this comprehensive perspective beyond
543 the national scale, to tie more firmly Italian researchers to international scientific networks on plant
544 traits.

545 We took note of species encountered while working at this review (looking at the considered papers
546 and related supplementary materials), which traits have been studied at least once on a population
547 located in Italy; we supply the species list in Appendix 2. We found a surprisingly high number of
548 traits available for 1080 vascular plants (of which only 3.2% endemics), mainly related to whole-
549 plant, leaf, seed, phenology and flowering traits. On the contrary, we registered a lack of traits
550 measurements for bryophytes and lichens. We also observed that functional traits of belowground
551 organs (root and clonal traits) have been often neglected, despite the fact that these traits are
552 extremely informative on resource acquisition strategies and other key functions, such as space
553 occupancy, recovery after damage (Lambers et al. 2006; Laliberté 2017; Ottaviani et al. 2017) as
554 well as other fundamental mechanisms such as plant-plant, plant-soil and plant-climate interactions.
555 Also the availability of wood traits measured in Italy, which include a time factor since they can be
556 dated within tree-ring series (Baas et al. 2016; Beeckman 2016), could represent a valuable step
557 forward in plant functional analysis at local scale. In the meantime wood traits are available in TRY
558 database (Kattge et al. 2011), or could be easily obtained from other sources (see Beeckman 2016).
559 We explored the TRY database (a global archive of plant traits, Kattge et a. 2011) founding traits
560 values for about 900 species deriving from Italian datasets (i.e. contributors with traits

561 measurements carried out in Italy). They were mainly related to leaf traits (Pierce et al. 2007a,b,
562 2012, 2013, 2014b; Cerabolini et al. 2010a,b; Campetella et al. 2011; Ciccarelli 2015; Burrascano et
563 al. 2015; Giarrizzo et al. 2017). Combining the above mentioned information and the data collected
564 in this review (Appendix 2), we gathered information on plant traits measured on Italian
565 populations for an overall total of 1418 taxa, which represent almost the 20% of the entire Italian
566 vascular flora (Bartolucci et al. 2018). Most of this information is shared in TRY database, but not
567 all (Figure 4). About 500 species whose traits measurements have been published in papers
568 considered in this review are not available in TRY. Moreover, 113 species among these (8% of the
569 1418 taxa) are totally missing in TRY database. It is therefore evident that Italian researchers can
570 easily give a more effective contribute to TRY database and to global research, by a complete share
571 of their own traits measurements already published in literature. This could lead to an improving of
572 the spatial coverage of the global archive of plant traits and give a crucial contribution regarding
573 plant communities still poorly investigated such as the Mediterranean region ones.

574

575 Plant traits approach hold promises in disentangling several issues still controversial in plant
576 ecology. For example, the assessment of determinants responsible of invasion potential of alien
577 species is crucial in light of the ongoing climate change. Recently, Petruzzellis et al. (2018)
578 compared several functional and mechanistic (*sensu* Brodribb et al. 2017) traits in a native and in an
579 alien species in sites under different light regimes, and suggested that a trade-off between hydraulic
580 safety and resource acquisition and use efficiency could promote aliens invasion. Plant-animal
581 interactions in pollination and dispersal, which influence the maintenance of plant populations and
582 communities (Fantinato et al. 2018a; Morales & Traveset 2008) have been scarcely investigated by
583 mean of plant traits. Recently floral traits, such as flowering phenology, floral morphology and
584 anther position, have been proved to influence the co-existence of co-flowering species in species-
585 rich communities (Fantinato et al. 2018b). Further investigations of trait-driven interactions might
586 open new perspectives on plant-plant co-existence (Pauw 2018).

587 Intraspecific Trait Variability, which has a strong effect on the sampling size and effort (Petruzzellis
588 et al. 2017), is still scarcely considered at population and community-level, while intraspecific
589 variability is often considered in ecophysiological studies. Moreover, we underline the need of
590 approaches evaluating trait-environment relationships at broad spatial and temporal scales, possibly
591 resulting from the collaboration of several research groups at national level, as well as analysis of
592 traits variations along ecological gradients, in order to make predictions about land use and climate
593 change impacts.

594 Italy could be a good regional model to explore emerging research fields in plant ecology, like those
595 related to ecosystem services and functional biogeography. There is a growing evidence that plant

596 traits considered at community-level have strong effects on ecosystem processes underlying
597 important ecosystem services (Suding & Goldstein 2008; Lavorel et al. 2010; Lavorel & Grigulis
598 2011). Also functional biogeography (i.e. the study of the geographic distribution of trait diversity
599 across organizational levels; Violle et al. 2014) could find a fertile ground in Italy, given its broad
600 biogeographical range.

601

602 **Authors contributions**

603 S.Ch., M.Ma., and E.Ba. promoted and coordinated the review; A.Pe., G.Pu., and C.We. contributed
604 to write the structure of the entire manuscript; A.Ac., E.Ba.,R.Bo., L.Br, G.Ca., A.Ch., L.Co.,
605 M.Ma., J.Na., S.Or., S.Pi., C.Ri., and F.Ta. organized the workshop "Plant traits 2.0" and/or revised
606 single chapters according to their expertise; B.Ce., S.Ch., M.Ma. and E.Ba. led the writing of the
607 conclusions; all the authors collected papers and revised the final version of the manuscript.

608

609 **Supplementary material**

610 **Appendix 1.** List of papers included in the review.

611 **Appendix 2.** List of species (vascular plants and bryophytes) for which there is the availability of
612 attributes measured in the field.

613

614

615

616

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1163 **Table 1.** Application fields of the most used plant functional traits in Italy with indications of the
 1164 number of papers and biogeographic region (A: Alpine; C: Continental; M: Mediterranean;
 1165 Roekaerts 2002).

Functional trait	Application field							
	Response to climate change	Response to different regimes of forest management	Response to grazing and land-use change	Response to other environmental gradients	Ecosystem functions	Succession	Invasiveness studies	Assembly rules
Whole-plant traits								
Growth form		1 ^M	1 ^A	7 ^C , 4 ^M			2 ^M	1 ^M
Life form	1 ^C	4 ^C , 1 ^M	1 ^A , 5 ^C	1 ^A , 2 ^C , 2 ^M		1 ^C	3 ^M	1 ^C , 1 ^M
Canopy height		2 ^C , 1 ^M	1 ^A , 7 ^C	6 ^A , 9 ^C , 8 ^M		1 ^A , 1 ^M	2 ^A , 2 ^C , 2 ^M	3 ^A , 2 ^C , 1 ^M
Leaf traits								
Specific leaf area	1 ^A , 1 ^C	2 ^C , 1 ^M	1 ^A , 4 ^C	8 ^A , 7 ^C , 7 ^M		1 ^A , 1 ^M	2 ^M	3 ^A , 2 ^C , 1 ^M
Leaf dry matter content	1 ^A		2 ^C	5 ^A , 6 ^C , 6 ^M		1 ^A , 1 ^M	2 ^M	3 ^A , 1 ^C
Leaf anatomy		3 ^C	3 ^C	1 ^C , 1 ^M				1 ^C
Leaf N	4 ^A , 1 ^C		2 ^C	8 ^A , 5 ^C , 2 ^M	2 ^A , 1 ^C			
Leaf persistence		1 ^C	5 ^C	3 ^C , 1 ^M			1 ^M	1 ^C , 1 ^M
Leaf thickness			1 ^M	5 ^C , 7 ^M				1 ^M
Leaf mass per area	2 ^M			6 ^C , 6 ^M				
Seed / Dispersal traits								
Seed germination	6 ^A , 1 ^C , 1 ^M			2 ^C , 1 ^M				
Seedling recruitment	1 ^A							
Seed dormancy	2 ^A			1 ^A , 1 ^C , 1 ^M				
Seed mass	1 ^A	5 ^C , 1 ^M	1 ^A , 3 ^C	4 ^A , 6 ^C , 6 ^M			1 ^A , 1 ^C	1 ^C , 2 ^M
Seed dispersal		4 ^C , 2 ^M		1 ^C , 3 ^M			2 ^M	
Phenology / Flowering traits								
Inflorescence production	4 ^A , 1 ^C		4 ^C					
Flowering time	3 ^A	4 ^C	7 ^C , 1 ^M	3 ^A , 7 ^C , 2 ^M		1 ^A	1 ^A , 1 ^C	3 ^A , 2 ^C , 1 ^M
Pollination system		2 ^C	1 ^A , 1 ^C	2 ^C , 2 ^M	1 ^M		2 ^M	1 ^M
Clonal traits								
Vegetative propagation		3 ^C , 2 ^M	7 ^C	2 ^C , 3 ^M			1 ^M	1 ^M
Lateral spread		3 ^C	1 ^C	2 ^A , 2 ^C			1 ^A , 1 ^C	2 ^A , 2 ^C
Spacers length		2 ^C	1 ^C	1 ^C				
Multiplication frequency		2 ^C		1 ^C				
Root traits								
Fine-root biomass		2 ^A	1 ^A	1 ^A , 1 ^M				
Fine-root turnover rate		2 ^A		1 ^M				
Fine-root C:N ratio		2 ^A	1 ^A					
Fine-root seasonal pattern		2 ^A						
Specific root length		2 ^A		1 ^M			1 ^M	
Biogeogr. Region representativeness (%)								
A	77	18	13	22	50	50	18	37
C	13	66	85	42	25	13	18	34
M	10	16	3	36	25	37	64	29

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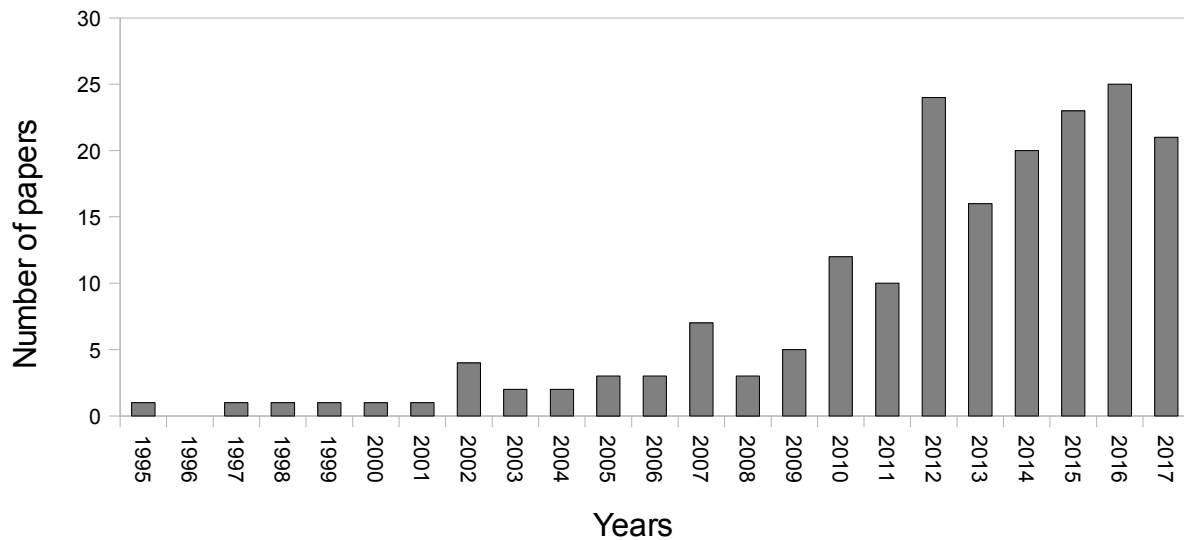
1179 **Table 2.** Main topics and related papers for each section.

Section	Topic	n	References
3.1. Impact of climate change on functional traits	Manipulation experiments: warmer conditions	8	Mondoni et al. 2012, 2015; Wellstein & Cianfaglione 2014; Orsenigo et al. 2015; Bernareggi et al. 2016, 2016; Carbognani et al. 2016; Gavrichkova et al. 2017
	Manipulation experiments: drought	3	Wellstein & Cianfaglione 2014; Orsenigo et al. 2017; Wellstein et al. 2017
	Manipulation experiments: reduced snow cover	1	Gerdol et al. 2013a
	Manipulation experiments: N and P deposition	6	Gerdol et al. 2002, 2008; Bragazza et al. 2012; Petraglia et al. 2013, 2014a,b
	Temporal gradients and space-for-time substitution	6	Bussotti et al. 2002; Abeli et al. 2012a,b; Dainese 2012; Salvatori et al. 2016; Evangelista et al. 2016
	Effects of climate change on lichens	6	Marini et al. 2011; Giordani et al. 2012; Favero-Longo et al. 2014; Nascimbene & Marini 2015; Nascimbene et al. 2017; Giordani et al. 2014c
3.2. Response of functional traits to forest management and eutrophication	Regeneration after coppicing	4	Canullo et al. 2011, 2017; Campetella et al. 2011; Catorci et al. 2012a
	Comparison between types of management	8	Scolastri et al. 2017; Montagnoli et al. 2012a; Terzaghi et al. 2013; Ricotta & Burrascano 2008; Burrascano et al. 2009; Nascimbene et al. 2007, 2008; Terwei et al. 2016
	Response to atmospheric deposition	3	Giordani et al. 2012, 2014; Giordani & Malaspina 2016
3.3. Secondary grasslands, grazing and land-use change	Comparison between land-uses	8	Catorci et al. 2011b,c,d; Catorci et al. 2012d; 2014a,b; 2013b; Targetti et al. 2013
	Gradients of stress and disturbance	6	Bagella et al. 2013a; Giordani et al. 2014a; Tardella & Catorci 2015; Catorci et al. 2016, 2017; Giarrizzo et al. 2017
	Abandonment under different environmental conditions	4	Halassy et al 2005; Wellstein et al. 2014; Corazza et al. 2016; Tardella et al. 2017
	Belowground and flowering traits	3	Montagnoli et al. 2010; Catorci et al. 2012b; Bagella et al. 2013b
3.4. CSR plant strategy theory	Environmental and climatic gradients	6	Pierce et al. 2007b, 2012; Cerabolini et al. 2010b, 2016; Gentili et al. 2013; Ciccarelli 2015
	Disturbance gradients	2	Pierce et al. 2007a; Cerabolini et al. 2010a
	Primary successions	4	Caccianiga et al. 2006; Gobbi et al. 2010; Ricotta et al. 2015, 2016
	Biotic gradients and relationships	3	Pierce et al. 2014a,b; Caccianiga et al. 2012
	Forest management and fragmentation	2	Catorci et al. 2011a; Buffa & Villani 2012
3.5. Plant functional traits and ecological processes in coastal ecosystems	Conservation status and invasive species	7	Malavasi et al. 2016; Prisco et al. 2016; Acosta et al. 2006; Stanisci et al. 2010; Pisanu et al. 2011; Jucker et al. 2013; Marcantonio et al. 2014
	Assembly rules	5	Carboni et al. 2013, 2016; Ricotta et al. 2014, 2015; Conti et al. 2017
	Functional aspects of specific taxa	3	Pisanu et al. 2011, 2012; Giordani et al. 2015a; Ciccarelli et al. 2016
3.6. Plant functional traits and intraspecific variability	Bryophytes	4	Gerdol 1995, 2002; Gerdol & Bragazza 2006; Spitale & Petraglia 2010
	Vascular plants under field conditions	12	Crescente et al. 2002; Gratani et al. 2012, 2014, 2018; Wellstein et al. 2013; Catorci et al. 2014c; Bauer et al. 1997; Kang et al. 2011; Montagnoli et al. 2012b, 2014; Puglielli et al. 2015a, 2017a
	Vascular plants under common garden conditions	5	Gratani et al. 2003; Catoni & Gratani 2013; Guet et al. 2015; Puglielli et al. 2017b; Peguero-Pina et al. 2017
3.7. Aquatic environments and plant growth: evidence from river and shallow inland ecosystems	Wetland origin, hydrology, water levels, biogeography	6	Bolpagni et al. 2013; Bolpagni & Piotti 2015, 2016; Lastrucci et al. 2016, 2017; Villa et al. 2015
	Physico-chemical water features	2	Bolpagni et al. 2014, 2015
	Sediment trophic level and chemistry	2	Lastrucci et al. 2016; Bolpagni & Pino 2017
	Time/seasons and phenological phases	3	Bolpagni et al. 2007; Pierobon et al. 2010; Villa et al. 2015
	Trade offs	1	Pierce et al. 2012

1181 **FIGURES**

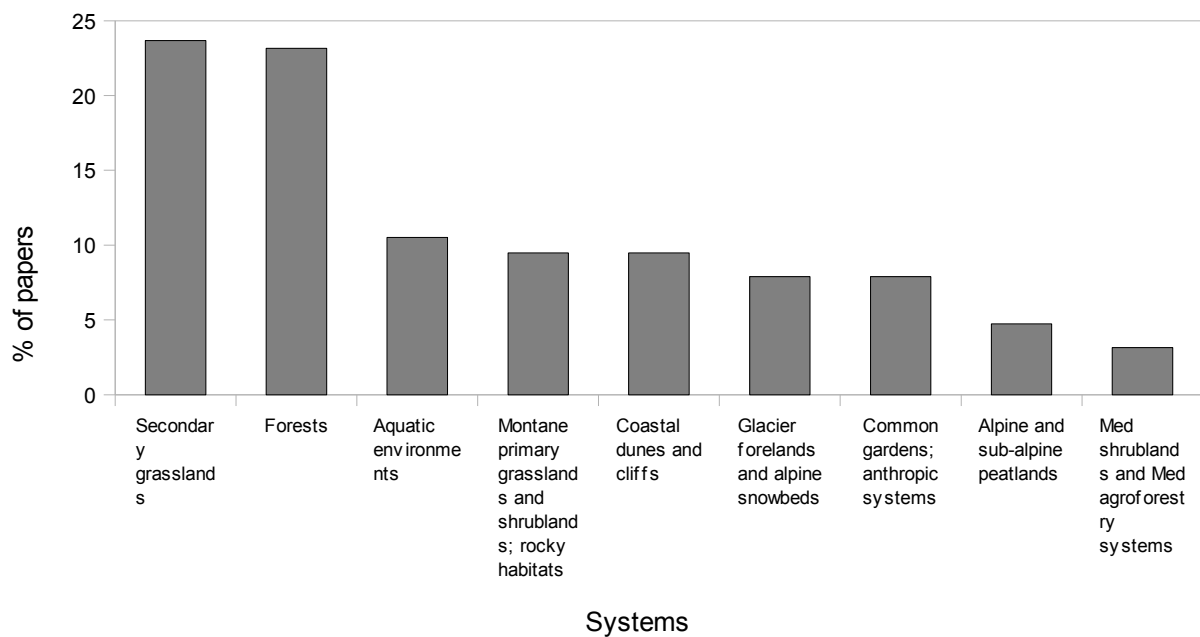
1182 **Figure 1.** Italian studies on functional traits in relation to environmental variables/gradients: (a)
1183 temporal trend in the number of papers published per year; (b) distribution of the collected
1184 papers regarding studied ecosystems; (c) number of vascular plant species accounted for the
1185 most frequently investigated functional traits.

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1188 **(b)**

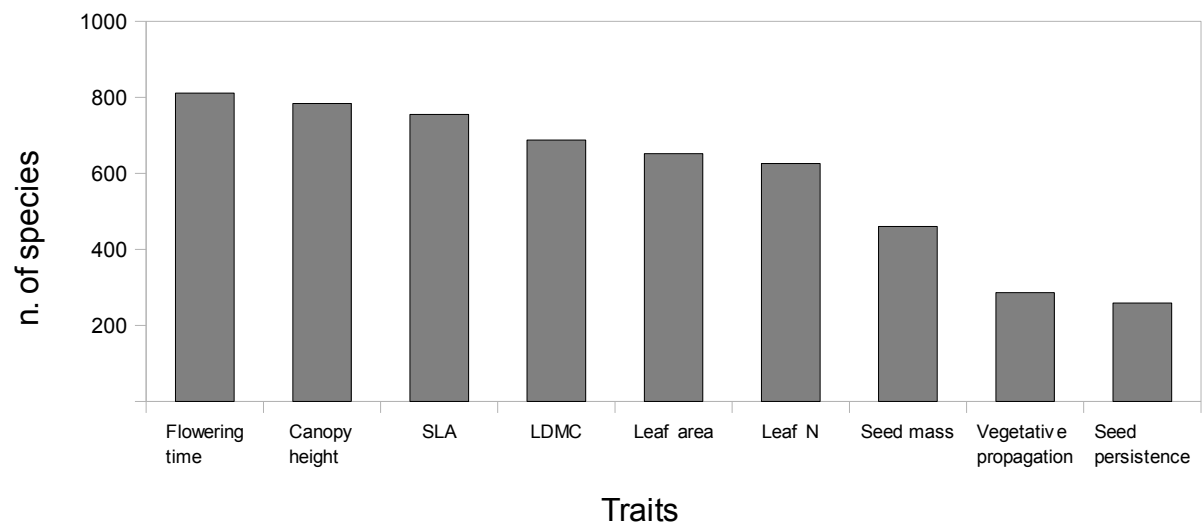


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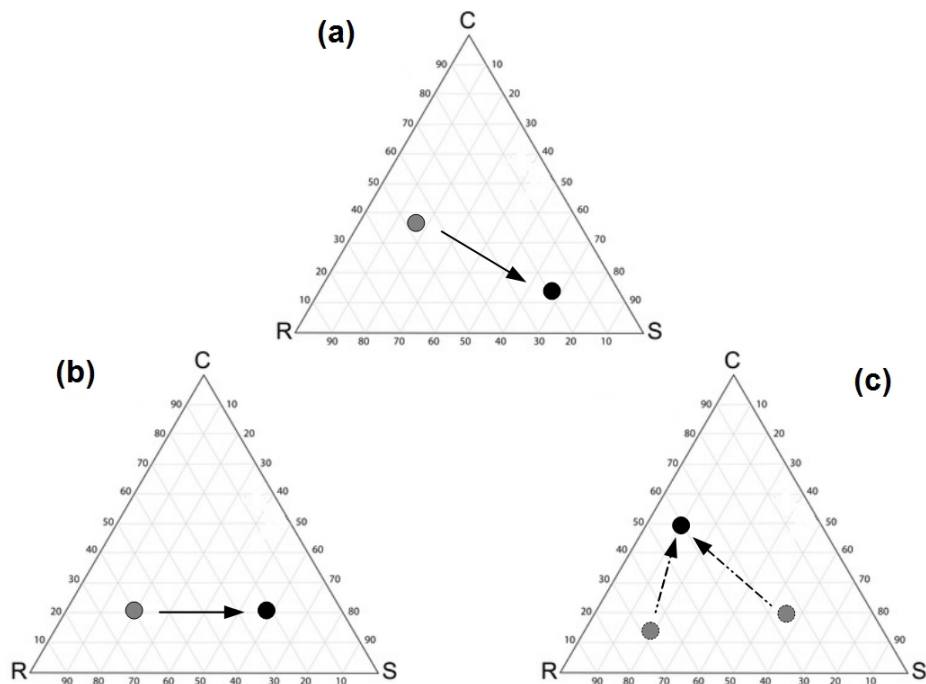
1192 (c)



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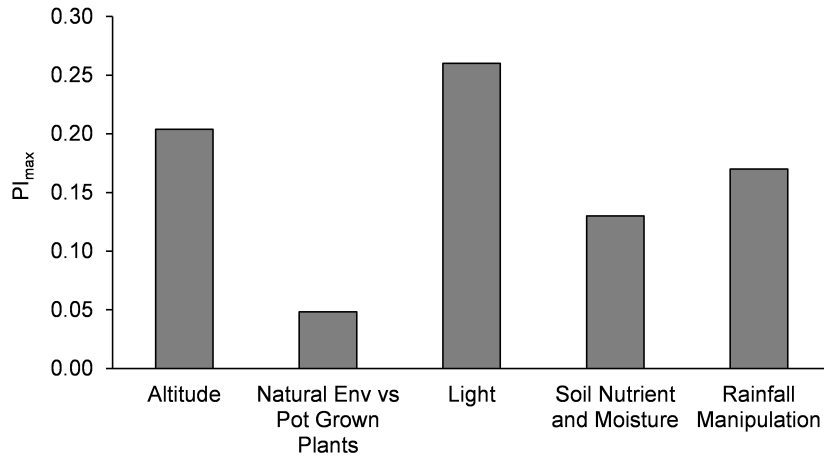
1195 **Figure 2.** CSR triangles synthesizing general mean strategies and shifts of vegetation along
1196 gradients of (a) increasing elevation (based on Caccianiga et al. 2006; Pierce et al. 2007a,b;
1197 Gentili et al. 2013), (b) primary successions, including glacier forelands and coastal dunes (based
1198 on Caccianiga et al. 2006; Gobbi et al. 2010; Ciccarelli 2015), and (c) grazing abandonment
1199 (based on Pierce et al. 2007a; Cerabolini et al. 2010a).
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1203 **Figure 3.** Maximum values of plasticity index (PI, sensu Valladares et al. 2000) of Specific Leaf
1204 Area for the endemic *Sesleria nitida* in different environments or along gradients (altitude,
1205 Gratani et al. 2014; natural environment vs. pot grown plants, Puglielli et al. 2015b; Light,
1206 Puglielli et al. 2015a; soil nutrient and moisture, Wellstein et al. 2013; rainfall manipulation,
1207 Wellstein et al. 2017).

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1213 **Figure 4.** Gathered information on plant traits of Italian populations deriving from our review
1214 (Appendix 2) and the Italian contributors to TRY, for an overall total of 1418 taxa, almost the
1215 20% of the entire Italian vascular flora (Bartolucci et al. 2018). Traits measurements of about
1216 900 species (65% of the 1418 taxa) are already shared in TRY database (i.e. species found both
1217 in the reviewed papers and in the Italian datasets contributing to TRY, or species found only in
1218 the Italian datasets contributing to TRY), while trait values for 502 species (35% of the 1418
1219 taxa) recorded by this review are not available in TRY; among these latter, 113 species (8% of
1220 the 1418 taxa) are totally missing in TRY.
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