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Impact of invasive alien plants on native plant communities and Natura 2000 habitats: State of the art, gap analysis and perspectives in Italy

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Abstract

Invasive alien plants are a major threat to biodiversity and they contribute to the unfavourable conservation status of habitats of interest to the European Community. In order to favour implementation of European Union Regulation no. 1143/2014 on invasive alien species, the Italian Society of Vegetation Science carried out a large survey led by a task force of 49 contributors with expertise in vegetation across all the Italian administrative regions. The survey summed up the knowledge on impact mechanisms of invasive alien plants in Italy and their outcomes on plant communities and the EU habitats of Community Interest, in accordance with Directive no. 92/43/EEC. The survey covered 241 alien plant species reported as having deleterious ecological impacts. The data collected illustrate the current state of the art, highlight the main gaps in knowledge, and suggest topics to be further investigated. In particular, the survey underlined competition as being the main mechanism of ecological impact on plant communities and Natura 2000 habitats. Of the 241 species, only *Ailanthus altissima* was found to exert an ecological impact on plant communities and Natura 2000 habitats in all Italian regions; while a further 20 species impact up to ten out of the 20 Italian administrative regions. Our data indicate that 84 out of 132 Natura 2000 Habitats (64 %) are subjected to some degree of impact by invasive alien plants. Freshwater habitats and natural and semi-natural grassland formations were impacted by the highest number of alien species, followed by coastal sand dunes and inland dunes, and forests. Although not exhaustive, this research is the first example of nationwide evaluation of the ecological impacts of invasive alien plants on plant communities and Natura 2000 Habitats.

Keywords:

Competition; Ecological impact; Expert survey; Impact mechanism; Impact outcome; Natura 2000 network

99 1. Introduction

100 Biological invasions are one of the most important drivers of biodiversity loss and ecosystem
101 degradation worldwide (Seebens et al., 2017). The establishment and spread of invasive alien
102 species (IAS) have affected multiple ecosystem processes, including community composition,
103 biotic interactions, and functions and services (Vilà and Hulme, 2017). Furthermore, IAS can also
104 impact important socio-economic assets, reducing the efficiency of natural resource exploitation,
105 affecting infrastructure effectiveness, and imposing costly management efforts (Bacher et al.,
106 2017). IAS are indeed one of the major drivers of changes in European habitats, and increase the
107 probability of unfavourable conservation status of natural habitats (Maes, 2013), causing a general
108 deterioration of biodiversity and the alteration of habitat structure and functions in plant
109 communities (Pyšek et al., 2012; Gigante et al., 2018). Therefore, it is an urgent and complex goal
110 in invasion biology to understand the mechanisms underlying biological invasions, one crucial to
111 predicting habitat invasibility (i.e. susceptibility to invasions) and recognising community response
112 to invasion in order to implement actions for the restoration and long-term management of
113 invaded habitats.

114 Despite there being a general awareness of the effects of invasive alien plants (IAPs), in Europe
115 there is still a lack of exhaustive works investigating the effects of IAPs on native plant
116 communities and on the habitats of Community Interest listed in the Habitats Directive (Council
117 Directive no. 92/43/EEC, hereafter N2000 Habitats) (Guerra et al., 2018). The N2000 network
118 proved to be crucial for preserving the EU's biodiversity, although there are increasing calls for
119 improvements and adjustments (Trochet and Schmeller, 2013; Friedrichs et al., 2018). The
120 importance of the N2000 network in tackling the risks posed by biological invasions was
121 underlined by the European Commission in the *EU 2020 Biodiversity Strategy*, and further
122 emphasised in the recent *EU 2030 Biodiversity Strategy*. However, there is still no common
123 approach for protecting the N2000 network, and its efficacy in decreasing the vulnerability to
124 invasive alien species is in large part still unknown (Guerra et al., 2018; Mazaris and Katsanevakis,
125 2018). Data on the presence and impact of IAS on the N2000 network is crucial to counter their
126 detrimental impacts, and of pivotal importance when considering the effects of climate change,
127 which are likely to increase the uncertainty associated with IAS performance (Guerra et al., 2018).
128 Indeed, protected areas and the N2000 network could become valuable tools to tackle the spread
129 of invasive species, especially in the light of future climate change (Gallardo et al. 2017).

130 In Italy, research on IAPs has gained momentum in the last 20 years (Lazzaro et al., 2019). Celesti-
131 Grapow et al. (2009) published the first comprehensive checklist, recently updated by Galasso et
132 al. (2018a). Several national projects and studies have been carried out in the last ten years (e.g.
133 Malavasi et al., 2018; Celesti-Grapow et al., 2016; Lazzaro et al., 2019). Nevertheless, scientific
134 literature concerning the impacts of IAPs in Italy is still patchy and there are no data for some taxa
135 and N2000 habitats.

136 In this context, the Italian Institute for Environmental Protection and Research (ISPRA)
137 commissioned a project to collect information on the impacts of IAPs on biodiversity and on the
138 N2000 network in Italy. The aim was to support national implementation of Regulation (EU)
139 1143/2014 on IAS. The study, designed and conducted by the Italian Society of Vegetation Science
140 (SISV), had two main aims: develop of a check-list of alien-dominated plant communities in Italy
141 (Viciani et al., 2020); and assess of the ecological impacts of IAPs on N2000 Habitats in Italy. To
142 achieve this second goal, we carried out a survey of the literature and of expert opinion that
143 involved a large number of botanist members of SISV. Specifically, this survey aimed at i) verifying
144 and listing IAPs known to affect native plant communities and N2000 Habitats on a regional and a
145 national scale, and ii) assessing the mechanism by which species make an impact and the possible

146 impacts exerted (i.e. impact mechanisms and impact outcomes, respectively, according to
 147 Blackburn et al., 2014) and iii) determining whether impact outcomes are exerted on specific
 148 N2000 Habitats. A supplementary aim was iv) to verify the presence of specific patterns of
 149 invasion in N2000 Habitats, hypothesising that the life form and the time since its first
 150 introduction may play a pivotal role in the threat posed by IAPs to Italian N2000 Habitats.

151 **2. Methods**

152 **2.1 Definitions and context**

153 We adopted the Regulation (EU) no. 1143/2014 definition of IAS as those “*whose introduction or*
 154 *spread has been found to threaten or adversely impact upon biodiversity and related ecosystem*
 155 *services*”. We focused on Ecological impacts, defined as “*a measurable change to the properties of*
 156 *an ecosystem by an alien species*”, considering only deleterious impacts, meant as “*any impact*
 157 *that changes the environment in such a way as to reduce native biodiversity or alter ecosystem*
 158 *function to the detriment of the incumbent native species*” (Blackburn et al., 2014). We included
 159 both natural and semi-natural ecosystems, considering only impacts affecting the native biota
 160 and/or ecosystem processes. Conversely, we did not consider either impacts on native species at
 161 the individual or population level, or any effect on human society (thus excluding any
 162 economic/social and health effects of IAPs).

163 We adopted the impact scheme of the Global Invasive Species Database (GISD 2020), as described
 164 in Blackburn et al. (2014), taking into account all possible impact mechanisms identified by the
 165 scheme, and all the ecological impact outcomes at the ecosystem/habitat level (see Table 1).

166 **Table 1.** Impact mechanisms and outcomes adopted in the survey of Italian IAPs. Each mechanism
 167 listed in the left column may result in one or more of the outcomes listed in the right column
 168 (Blackburn et al., 2014).

169

Impact mechanism	Impact outcomes exerted at the ecosystem/habitat level
Competition	Modification of hydrology/water regulation, purification and quality /soil moisture
Predation	Primary production alteration
Hybridization	Modification of nutrient pool and fluxes
Disease transmission	Modification of natural benthic communities
Parasitism	Modification of food web
Poisoning/Toxicity	Reduction in native biodiversity
Bio-fouling	Unspecified ecosystem modification
Grazing/Herbivory/Browsing	Habitat degradation
Rooting/Digging	Habitat or <i>refugia</i> replacement/loss
Trampling	Physical disturbance
Flammability	Modification of fire regime
Interaction with other invasive species	Modification of successional patterns
Others	Soil or sediment modification: erosion
	Soil or sediment modification: bioaccumulation
	Soil or sediment modification: modification of structure
	Soil or sediment modification: modification of pH, salinity or organic substances
	Other

170

171 The nomenclature of IAPs follows Galasso et al. (2018a). As the assessment of the effects of IAPs
172 on habitats of community interest made up a pivotal part of our data collection, to define the
173 habitats we followed the “Italian Interpretation Manual of the 92/43/EEC Habitats Directive”
174 (Biondi et al., 2009) and the Interpretation manual of European Union EU28 (European
175 Commission, 2013).

176

177 **2.2 Survey strategy**

178 Our evaluation of the current impact outcomes of IAPs in Italy was based on a survey of the
179 literature and expert opinion. The working group was composed of 49 members of the SISV (the
180 co-authors of the present work – mainly technicians or academic botanists, with expertise in
181 vegetation science, N2000 Habitats and IAPs), who provided data and their knowledge of the
182 situation at the local (regional) level or regarding specific IAPs.

183 We provided each expert with a spreadsheet template that included specific guidelines on the
184 type of data required and how to fill in the spreadsheet (see Appendix 1). The template included
185 an initial list of 184 IAPs established in Italy, taken from the National Alien Plant Species Data Base
186 (Lazzaro et al., 2019). The contributors were asked to provide data on impact mechanisms and
187 outcomes in their region in accordance with Blackburn et al. (2014), see Table 1. Particularly, for
188 each species of the list, experts were asked to provide the following information: a) impact
189 mechanism, b) impact outcomes, c) impact outcomes with specific reference to N2000 Habitats, d)
190 data source, specifying whether it originated from i) scientific literature, ii) technical reports or
191 grey literature or iii) expert assessment, and e) the level of uncertainty of the data provided. In
192 addition, contributors were encouraged to add to the list any further IAPs found to have an
193 impact.

194 The survey strategy adopted in the study followed the framework of the consensus-building
195 approach (see Vanderhoeven et al., 2017), in which several rounds of structured questionnaires,
196 with subsequent aggregation of responses followed by feedback to the experts, are used to
197 reduce inconsistencies among assessors. In our case, in a first round of evaluation, the
198 contributors were asked to fill in the template individually, after reading the guidelines and the
199 referenced documentation. Data from this preliminary collection (which ended on 2017 July 31)
200 were aggregated and presented to all contributors during a two-day workshop (2017 October 16-
201 17), to discuss possible shortcomings and identify knowledge gaps and dissimilarities in the data
202 collection. After the workshop, we opened a second call (conclusion in 2017 December) to allow
203 all the contributors to homogenize the data provided and overcome the shortcomings that
204 emerged during the workshop.

205 **2.3 Data analyses**

206 **2.3.1 Breakdown of results on IAPs and impacts outcomes and mechanisms**

207 The data obtained on the impacts (mechanisms and outcomes) of IAPs on plant communities and
208 N2000 Habitats were merged into a single table. The data were cleaned and standardized, spelling
209 mistakes were corrected and duplicate records were deleted. Data were organized to depict the
210 overall patterns of IAP distribution across Italian regions, and to outline patterns of impact
211 mechanisms and outcomes on native plant communities and N2000 Habitats at species and
212 administrative regions levels.

213 **2.3.2 Patterns of invasion on N2000 Habitats**

214 With the aim of detecting specific trends of invasion, for all IAPs assessed as having an impact on
215 N2000 Habitats at a national level, we collected further data regarding a) the life form, b) the
216 number of administrative regions colonized (according to Galasso et al., 2018a and subsequent
217 updates, Galasso et al., 2018b; 2018c) and c) the date of the first introduction in Italy (information
218 retrieved from literature and technical sources, see Appendix 2). However, although of paramount

219 importance, data on the time of introduction is not entirely reliable, since it may correspond
220 either to the date of the first introduction in botanical gardens or to the first detection in nature.
221 Accordingly, we chose to reclassify neophytes into three main groups: 1) introduced between
222 1492 and 1800, 2) introduced between 1800 and 1950 and 3) introduced from 1950 to date
223 (2020). This grouping (hereafter named introduction period) reflects the main changes in global
224 human flows, passing from the age of geographical discoveries to the XIX century (1492–1799),
225 from colonialism to the industrial revolution and the two world wars (1800–1950), and finally from
226 the time of the economic boom to globalisation (1951–2020).

227 We excluded from the analysis all the species introduced before 1492 (archaeophytes) (only eight
228 species among those exerting impacts on N2000 habitats: *Abutilon theophrasti*, *Arundo donax*,
229 *Cuscuta cesatiana*, *Cyperus esculentus*, *Cyperus serotinus*, *Isatis tinctoria* subsp. *tinctoria*, *Ricinus*
230 *communis*, *Sorghum halepense*), and *Salvinia molesta*, whose presence in Italy is doubtful.

231 We analysed impacts on single N2000 habitats (as indicated by the entire N2000 code, e.g. 1210)
232 and then on macro-categories, as indicated by the first number of the N2000 code (e.g. 1: coastal
233 habitats, 2: dune habitats and so on; see European Commission, 2013). To avoid possible biases
234 due to the uneven number of habitats across administrative regions, the analyses were conducted
235 at the national level (i.e. we used number of habitats and habitat macro-categories invaded by the
236 species in Italy).

237 To investigate the correlation between the number of habitats, the number of macro-categories of
238 habitats and the number of colonized administrative regions, we ran a correlation analysis for
239 each introduction period, we calculated the pairwise Spearman's rank correlation coefficient
240 (Spearman's ρ) and evaluated its significance by means of the asymptotic t approximation.

241 Finally, we ran a series of generalized linear models (GLM) to study the effect of the introduction
242 period and of the life form categories on the number of invaded N2000 habitats, the number of
243 invaded N2000 habitat macro-categories, and the number of invaded administrative regions.

244 Given the overdispersion of our data, we adopted a quasi-Poisson distribution and evaluated the
245 significance of the terms with an ANOVA table. All the analyses were conducted in R environment
246 vers. 3.6.1 (R Core Team 2019).

247 **3. Results**

248 **3.1 Breakdown of results on IAPs and impacts outcomes and mechanisms**

249 We collected data on 241 IAPs, 57 more than the 184 originally indicated in the template (see
250 Appendix 2). Only a few species were reported in a high number of administrative regions and by
251 several contributors. In general, degree of knowledge varied substantially between regions, as
252 shown by the variation in numbers of regional records on impact mechanisms and outcomes (Figs.
253 1A and 1B). The number of IAPs assessed as having an ecological impact (Fig. 1C) and the
254 distribution of impacts on N2000 habitats (Fig. 1D), varied widely between administrative regions.
255 Similarly, compared to the total number of habitats harboured in a given region, the percentage of
256 those exposed to some degree of ecological impact was very variable, with Lombardy and Friuli-
257 Venezia Giulia having more than half of the habitats impacted by IAPs, followed by Molise and
258 Sardinia (Fig. 1E). Variability also characterized the relationship between species and their impact
259 mechanisms and outcomes. Indeed, most IAPs had very few reports of mechanisms of impact—220
260 out of 241 species had less than five reports of impacts—while only a handful of species had a high
261 number of records. A similar situation was found as far as impact outcomes are concerned: most
262 of the species had very few reports and very few species had a high number of records (see Fig. 2).
263 Of the impact mechanisms, "*Competition*" was the most frequent, being common to around 83%
264 of reports, followed by "*Unknown*" mechanism (4%), "*Interaction with other invasive species*" (4%)
265 and "*Poisoning/toxicity*" (3%).

266 *Ailanthus altissima*, listed in all Italian administrative regions, was the species with the highest
267 number of records of impact mechanisms. Competition was the main impact mechanism assigned
268 to the species, followed by “*Rooting/digging*”. Further species with a very high number of records,
269 such as *Senecio inaequidens*, *Robinia pseudoacacia*, *Helianthus tuberosus* and *Sorghum halepense*,
270 were all assessed as invaders with a high degree of impact in many administrative regions (see Fig
271 3A for main mechanisms of the first 23 species). Nevertheless, despite a high number of impact
272 reports, most data—62%—came from expert assessments that were not experimentally verified
273 (Fig. 4 A). Only 25% of the reports were retrieved from the scientific literature and 13% from
274 technical reports and grey literature.

275 Species most frequently recorded for impact outcomes differed from those most frequently
276 recorded for impact mechanisms: *Robinia pseudoacacia* was the species with the highest number
277 of impact outcome records, followed by *Acacia saligna*, *Amorpha fruticosa*, *Arundo donax*,
278 *Ailanthus altissima*, *Carpobrotus edulis*, *C. acinaciformis*, *Helianthus tuberosus*, *Senecio*
279 *inaequidens*, and *Solidago gigantea* (Fig 3B). As with impact mechanisms, most of the records
280 (78%) were from expert assessments, while 13% were retrieved from technical reports and grey
281 literature, and only 9% from the scientific literature (Fig. 4B).

282 Reduction in native biodiversity was by far the most reported outcome, followed by general
283 habitat degradation, loss of habitat and refugia, and modification of successional patterns (Fig.
284 5A). The ranking of threats posed to N2000 Habitats showed the same order. Indeed, a reduction
285 in native biodiversity was cited for nearly all N2000 habitats present in Italy (81 out of 84),
286 followed by the same outcomes named above (Fig. 5B).

287 Nonetheless, impacts were unevenly distributed, especially in terms of the number of IAPs
288 impacting specific habitats, and less in terms of the number of administrative regions in which the
289 target N2000 habitat is impacted (Fig. 6A-B). N2000 Habitat 3270 was by far the one impacted by
290 the highest number of invasive species (79 species), followed by N2000 Habitat 6430. At the
291 macro-category level, freshwater habitats (N2000 Habitats 3xxx) and natural and semi-natural
292 grassland formations (N2000 Habitats 6xxx) were impacted by the highest number of alien species,
293 followed by coastal sand dunes and inland dunes (N2000 Habitats 2xxx), and forests (N2000
294 Habitats 9xxx). In terms of the regional distribution of impacted habitats, freshwater habitats were
295 generally affected in many regions, with coastal sand dunes, coastal and halophytic habitats
296 (N2000 Habitats 1xxx) and forests also being frequently affected (Fig 6 B).

297 **3.2 Patterns of invasion on N2000 Habitats**

298 The 241 IAPs recorded in our survey included 167 neophytes invading the N2000 habitats; 29
299 species were introduced before 1800, 84 between 1800 and 1950, and 54 after 1950 (Appendix 2).
300 Therophytes (56 species) and phanerophytes (45) were the most frequent life forms, followed by
301 hemicryptophytes (19), geophytes (17), chamaephytes (16), and hydrophytes (14). *Ailanthus*
302 *altissima*, *Robinia pseudoacacia*, *Senecio inaequidens*, *Amorpha fruticosa*, and *Carpobrotus edulis*
303 were the most frequent invaders both in N2000 habitats (28, 25, 23, 17, 16 each respectively) and
304 in habitat macro-categories (7, 7, 8, 6, 5 respectively), although with slightly different rankings
305 (see Appendix 2). The number of habitats and that of habitat macro-categories invaded correlated
306 strongly for all three periods (p value < 0.001 , see Table 2), although the correlation decreased
307 slightly from the first introduction period (before 1800; $p = 0.930$) to the last (from 1950 to date; p
308 $= 0.845$). Showing a more strongly decreasing trend, the number of regions colonised was
309 significantly correlated with the number of habitats ($\rho = 0.523$, p value $= 0.003$) and macro-
310 habitats invaded ($\rho = 0.489$, p value $= 0.007$) only for the first introduction period (before 1800);
311 while no significant correlation was found for the other two introduction periods (Table 2).
312 Life form categories significantly affected the distribution of species in terms of number of invaded
313 N2000 habitats and macro-habitats, as well as in terms of number of colonised administrative

314 regions (Table 3). Overall, chamaephytes were the most widespread invaders, invading the highest
 315 number of habitats (and habitat macro-categories), followed by geophytes, phanerophytes and
 316 therophytes; hydrophytes were specific to a small number of habitats (Figs. 7A, C). On the other
 317 hand, therophytes had spread into the highest number of regions, together with geophytes (Fig.
 318 7E). Introduction period strongly affected the number of habitats, of habitat macro-categories,
 319 and of administrative regions invaded (Table 3). Indeed, the longer a species had been introduced,
 320 the higher the number of invaded habitats, macro-habitats and administrative regions (7 B, D, F).
 321 **Table 2** Matrices of correlation between the number of N2000 habitats (Habitats), number of
 322 macro-categories of N2000 habitats (Macro-habitats) and number of invaded administrative
 323 regions (Regions), for each introduction period. In each correlation matrix, the upper triangle
 324 (numbers in plain text) displays Spearman's rank correlation coefficient (Spearman's rho), while
 325 the lower triangle (numbers in italic) displays its significance.

Introduction Period		Macro		
		Habitats	Macro-habitats	Regions
1492 – 1799	Habitats	-	0.930	0.523
	Macro-habitats	<i><0.001</i>	-	0.489
	Regions	<i>0.003</i>	<i>0.007</i>	-
1800 – 1950	Habitats	-	0.860	0.129
	Macro-habitats	<i><0.001</i>	-	0.187
	Regions	<i>0.129</i>	<i>0.187</i>	-
1951 – present	Habitats	-	0.845	0.077
	Macro-habitats	<i><0.001</i>	-	0.096
	Regions	<i>0.579</i>	<i>0.488</i>	-

326
 327 **Table 3** Analysis of the deviance table for the generalized linear models analysing the effect of life
 328 form categories and introduction period on the number of invaded N2000 Habitats (Habitats),
 329 number of macro-categories of N2000 Habitat (Macro-habitats) and number of invaded
 330 administrative regions (Regions). χ^2 = Likelihood ratio Chi-square; Df = Degree of freedom;
 331 Significance codes: P value < 0.001 '***'; P value < 0.05 '*'.

Response	Term	χ^2	Df	P value	
Habitats	life form	24.576	5	<0.001	***
	introduction period	28.551	2	<0.001	***
	life form×introduction period	12.005	10	0.285	
Macro-habitats	life form	23.720	5	<0.001	***
	introduction period	28.723	2	<0.001	***
	life form×introduction period	15.669	10	0.109	
Regions	life form	13.725	5	0.017	*

introduction period	52.092	2	<0.001	***
life form×introduction period	15.691	10	0.109	

4. Discussion

Our data showed that the general impact of IAPs on native plant communities and N2000 Habitats has still only been partially unravelled at the national level. Specifically, our study brought to light two main problems. One is that that very few data are available on the mechanisms by which IAPs exert their impact. This lack greatly reduces our ability to implement effective adaptive strategies to counteract the spread and the effects of IAPs. In addition to this, the data that are available are very unevenly distributed between regions, further reducing our capacity to understand the nation-wide effects of IAPs. Filling these gaps calls for an urgent nation-wide collaborative initiative with coordinated action programs and standard methodologies. The initiative would ideally be conducted under the auspices of ISPRA or of the Italian Ministry of the Environment and Preservation of Land and Sea, which provided funding and motivation for the present study. Also, the establishment of a national collaboration between numerous Italian research groups to participate in joint projects at the EU level (i.e. within EU LIFE programme or Horizon Europe 2021-2027), or within national scientific societies like SISV or the Italian Botanical Society (SBI), is essential to complete the picture of alien species invasion in Italy.

The differences between the impacts recorded for different Italian regions are consistent with the findings of the main catalogues of alien plants in Italy (Galasso et al., 2018a; Celesti-Grapow et al., 2009). The highest number of records was observed in the largest and most densely populated regions (i.e. Lombardy, Piedmont, and Tuscany), where human-driven land cover changes like urbanization, industrialisation, road infrastructures, and agriculture, cause higher rates of introduction (McLean et al., 2017), thereby facilitating biological invasion. The intensification of agricultural use of land has been proven to play a crucial role in the introduction, establishment and spread of IAPs due to a decline in biodiversity caused by oversimplified landscape matrices (Walker et al., 2009; Buffa et al., 2018). This is especially true for lowland riverscapes which suffer from the deterioration of water, of sediments and of hydrological regimes (Bolpagni and Piotti, 2015; Bolpagni et al., 2013), situations that have been identified as common key factors driving the establishment and spread of IAPs in newly invaded areas (Aronson et al., 2017).

However, comparatively large and densely populated regions (e.g. Lazio, Emilia-Romagna) did not show the same degree of invasion. This difference could be the result of contrasting levels of awareness between the different administrative regions in Italy. A minority of regions have already adopted specific regulatory frameworks to address the issue of biological invasions (Brundu et al., 2020), while the other regions still pay little attention to this matter. Only Lombardy, Piedmont, Aosta Valley have a list of restricted IAPs, approved by regional laws, and working groups dedicated to IAPs. In Friuli-Venezia Giulia and Tuscany only few IAPs are considered in regional laws. Finally, Liguria has established a surveillance network and a permanent working group on IAS within the Italian-French ALIEM Project. To our knowledge, all the other Italian administrative regions lack a local regulatory framework on IAPs, even if the recent promulgation of legislative decree no. 230/2017 calls for a comprehensive framework to tackle this issue. We are convinced that a decisive contribution to this matter would come from the establishment of a national list of invasive alien species of Member State (Italy) concern (see Art. 12 of Regulation (EU) no. 1143/2014), under the guidance of the Italian Ministry of the Environment and Preservation of Land and Sea. To this end, an important action aimed at the

374 individuation of candidate species for the implementation of such a list (see Lazzaro et al., 2019) is
375 currently being carried out by ISPRA, within the Life ASAP project (LIFE15 GIE/IT/001039).
376 The high number of expert-based assessments in our survey underscores the major difficulty in
377 retrieving suitable and reliable literature on the impacts of IAPs in Italy. Indeed, direct evidence is
378 frequently also lacking for very well-studied species, generally considered a priori to be a serious
379 threat to biodiversity. The gaps in knowledge of the different taxa hinder the study (and
380 management) of the impacts associated with biological invasions, with most papers focusing on a
381 narrow set of already studied species (Hulme et al., 2013; Latombe et al., 2017). This is especially
382 serious because data on impacts are necessary to lay the basis for any generalisation about
383 biological invasions and are mandatory for risk assessment and management (Bolpagni et al.,
384 2014a; Lazzaro et al., 2015).

385 For example, information concerning *A. altissima* mainly comes from regional reports and
386 checklists which often lack direct measurements of the cited impacts (see Badalamenti et al.,
387 2016; Maiorca et al., 2007). Although the impacts caused by this species are relatively well-studied
388 (Castro-Díez et al., 2019), impacts in Italy are only documented for Sardinia (Traveset et al., 2008;
389 Vilà et al., 2006) and the Karst area in northeastern Italy (Uboni et al., 2019) and there is very little
390 literature on impacts outcomes on plant communities or on N2000 Habitats. Among the most
391 studied species, *Robinia pseudoacacia* stands out as a major invasive tree in Europe (Vítková et al.,
392 2017). Many studies in Italy have focused on the impacts of this species (Nascimbene et al., 2012,
393 2015; Benesperi et al., 2012; Lazzaro et al., 2018; Sitzia et al., 2018; Campagnaro et al., 2018;
394 Gentili et al., 2019). Most authors have found evidence that the rapid expansion of this species in
395 Italy is causing the progressive decline of native forests, with loss of species richness and diversity
396 and a shift in species composition towards nitrophilous assemblages (Benesperi et al., 2012;
397 Lazzaro et al., 2018; Allegrezza et al., 2019). In contrast, other authors have shown that secondary
398 *Robinia* forests, growing on abandoned lands, may host compositionally heterogeneous plant
399 communities and may contribute to some degree to regional biodiversity (Campagnaro et al.,
400 2018). Nevertheless, as pointed out also by Lazzaro et al. (2018), it is worth mentioning that in
401 many cases *Robinia* forests replace habitats considered of community interest in Europe (i.e.
402 N2000 Habitats 9260, 91B0, 91M0, 91AA*; Montecchiari et al., 2020, and 92A0 among others).
403 *Robinia pseudoacacia* is also an important forest species, so that one option would be to apply
404 forestry best practice to avoid its escape from areas set aside for cultivation.

405 *Robinia pseudoacacia* is also predicted to be one of the most competitive species in a climate
406 change scenario (Kleinbauer et al., 2010), and recently Nascimbene et al. (2020) showed the
407 effects of the interaction between climate change and invasion by *R. pseudoacacia* on the
408 endangered lichen species *Lobaria pulmonaria*. Biological invasions and climate change (often
409 referred to as “double trouble”) are considered two of the key drivers of biodiversity loss, whose
410 interaction will lead to a magnification of the threats to biodiversity worldwide (Mainka and
411 Howard, 2010).

412 Among the highly invasive tree species, in Northern Italy *Prunus serotina* and *Quercus rubra* have
413 also been reported to greatly impact native communities and ecosystem components at the soil
414 level (Gentili et al., 2019; Vegini et al., 2020). *Acacia* is another genus well-studied in Italy and
415 worldwide. The negative impacts on plant communities of these nitrogen-fixing trees are well
416 documented for several species (e.g., *A. dealbata*: Lazzaro et al., 2014; Minuto et al., 2020; *A.*
417 *pycnantha*: Lazzaro et al., 2015). Likewise, the impacts of *A. saligna* on coastal dune N2000
418 habitats (Del Vecchio et al., 2013; Bonari et al., 2017; Calabrese et al., 2017).

419 *Carpobrotus acinaciformis*, *C. edulis* and their hybrids (Campoy et al., 2018), is another group of
420 invasive species widely investigated in Italy, whose impacts on both biodiversity (Santoro et al.,
421 2012; Jucker et al., 2013) and soil conditions (Zedda et al., 2010; Santoro et al., 2011; Badalamenti

422 et al., 2016) are well depicted. Their pattern of occurrence at the community level (Carboni et al.,
423 2010; Sperandii et al., 2017) as well as their habitat preference, including N2000 Habitats 2120,
424 2210 and 2250*, have also been studied (Sarmati et al., 2019).

425 Some specific studies have focused on the impact of different IAPs (e.g. *Ambrosia psilostachya*,
426 *Cenchrus longispinus*, *Erigeron canadensis*, *Oenothera stueckii*, *Senecio inaequidens*) on sand dune
427 ecosystems in northeastern Italy, showing significant negative effects on species richness, species
428 diversity and evenness, and plant community composition, with effects increasing from N2000
429 drift line habitats (1210) to fixed-dune habitats (2130) (Del Vecchio et al., 2015).

430 Unfortunately, once these few well-studied IAPs are excluded, most of the records of impact on
431 plant communities and N2000 habitats collected in the present general assessment derive from
432 expert evaluations. This applies in particular to the species listed among the Invasive Alien plant
433 Species of Union Concern (*sensu* Regulation (EU) no. 1143/2014), both because their spatial
434 distribution in Italy is still scattered or localized (e.g. *Alternanthera philoxeroides*, *Pontederia*
435 *crassipes*) and especially because data on their impacts is still missing (with only a few exceptions;
436 see e.g. Lastrucci et al. (2017) for *Myriophyllum aquaticum*). The lack of information may also be
437 due to the difficulty in obtaining reliable data for plants and vegetation in aquatic ecosystems,
438 normally extremely time- and money-consuming to sample (Azzella et al., 2017). Indeed, half of
439 the IAPs of Union concern are aquatic or wetland plants (19 out of 36). Despite their high number
440 in the EU list confirming the general poor state of conservation of inland waters (Brundu, 2014;
441 Lastrucci et al., 2017), aquatic IAPs have been so far neglected or little investigated in Italy.

442 However, several studies confirmed their pivotal role in reducing local biodiversity. Bolpagni
443 (2013a; 2013b) and Bolpagni et al. (2017) found that *Lagarosiphon major* and *Elodea nuttallii*
444 create extensive submerged meadows that almost completely replace native macrophyte
445 communities belonging to N2000 habitats 3140 and 3150. *Nelumbo nucifera* and *Ludwigia*
446 *hexapetala* seem to actively compete with native species (Bolpagni et al., 2014b; Villa et al., 2017;
447 2018; Tóth et al., 2019) due to their enhanced competitive ability for limiting resources and their
448 tolerance to edaphic conditions variability (Tóth et al., 2019). Some specific studies focused on the
449 impact of *Lemna minuta* on freshwater ecosystems. The results highlighted substantial negative
450 effects on water quality and on aquatic plant and animal communities (Ceschin et al., 2019; 2020),
451 showing that *L. minuta* causes drastic alterations to the local vegetation, often replacing native
452 species. Similar results have been found for the most common duckweed, *L. minor*, which
453 assimilates available nutrients faster than native species and shows a higher relative growth rate
454 (Ceschin et al., 2016a, 2016b), characteristics that make this species highly competitive. However,
455 the scarcity of knowledge on the majority of aquatic IAPs hinders both a correct assessment of the
456 environmental impacts and the planning of actions to be carried out for effective recovery of
457 impacted ecosystems.

458 Our survey also evidenced a group of well-known and widespread invasive herbs (i.e., *Amaranthus*
459 *retroflexus*, *Ambrosia artemisiifolia*, *Artemisia verlotiorum*, *Bidens frondosa*, *Erigeron canadensis*),
460 that are very competitive in disturbed habitats (agricultural areas, roadsides, ruderal areas) also
461 thanks to their high propagule pressure. Ruderal species are highly opportunistic and it is worth
462 mentioning the presence of *Phytolacca americana* and *Solanum chenopodioides* in an old-growth
463 *Quercus ilex* urban forest disturbed by a severe windstorm in Southern Italy (Bonanomi et al.,
464 2018). Opportunistic alien species, which invest in rapid growth and in sexual reproduction, are a
465 challenging issue in invasion biology since their invasiveness may change during different
466 successional stages (Domènech and Vilà, 2006). For instance, the annual *A. artemisiifolia* is
467 completely suppressed by late colonists and perennial species after a three-year succession
468 (Gentili et al., 2017). Conversely, the invasion of *Solidago canadensis* has been reported to modify

469 the trajectory of vegetation succession and to exert a higher negative effect on native diversity in
470 older successional communities (Fenesi et al., 2015a; 2015b).

471 Finally, this survey showed that the time elapsed since introduction has a highly significant
472 effect on the number of habitats invaded. This highlights the importance of better investigating
473 species of relatively recent introduction, which are not yet truly invasive, but which have
474 considerable potential to invade given the size of the introduced populations. These include some
475 species of *Eucalyptus*, especially *E. camaldulensis*, which in recent years has begun to spread in
476 river habitats in Sicily (Badalamenti et al., 2018). In this, as in other cases, biological evolution acts
477 on the introduced species and may enable some alien plants to occupy a broad range of novel
478 habitats until they become invasive (Oduor et al., 2016). Tree species should be carefully
479 monitored because although they take time to become invasive, when they do, the impact is high
480 because of their large biomass.

481 **5. Conclusions**

482 Our survey is the first attempt to assess the impact of the most harmful IAPs on plant communities
483 and on N2000 habitats throughout Italy. The study highlighted numerous knowledge gaps which,
484 however, replicate the gaps in plant invasion science ascertained at a global level. The differences
485 in levels of knowledge between the Italian administrative regions is likely linked to dissimilarities
486 in awareness, as shown by regional differences in policies and legislation. Thus, a primary aim of
487 the scientific community should be to even up disparities in knowledge at the regional level. Most
488 importantly, we highlighted a glaring lack of evidences, even for well-known invasive species. We
489 also exposed a lack of data on the impacts of IAPs on N2000 habitats, which ought to be a primary
490 focus of conservation efforts. Thus, filling the knowledge gap is a mission of primary importance,
491 to provide data both for risk analysis and to support decision makers. Our results show that Italy
492 needs a coordinated nation-wide strategy to evaluate and manage the risk of invasion in the
493 N2000 network. This need is even more urgent in the light of the compounded effects of biological
494 invasion and climate change, which biodiversity management planning and policy should take into
495 careful consideration.

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500 **Author contributions**

501 L.Las., R.Bol., L.Laz., G.Buf. and F.Bra. were involved in designing the methodology and
502 coordinated the work for the data collection on behalf of Italian Society of Vegetation Science.
503 L.Laz., L.Las., R.Bol., G.Buf., R.Gen., M.Lon. and A.Sti. were involved in data analysis and
504 interpretation and drafting the manuscript. All authors provided data for the survey as associated
505 of SISV, critically revised the draft of the manuscript and gave final approval for publication.
506

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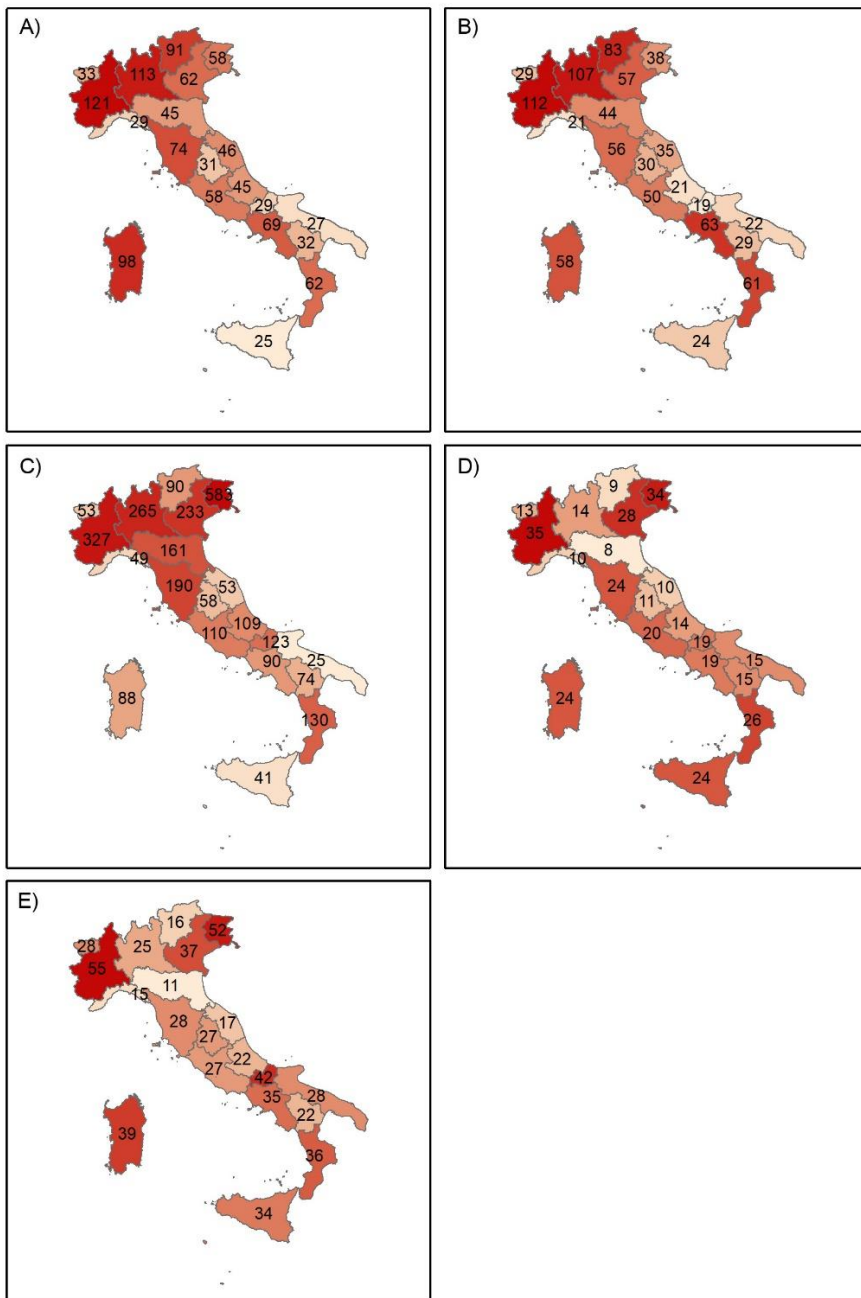
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849 **FIGURES**

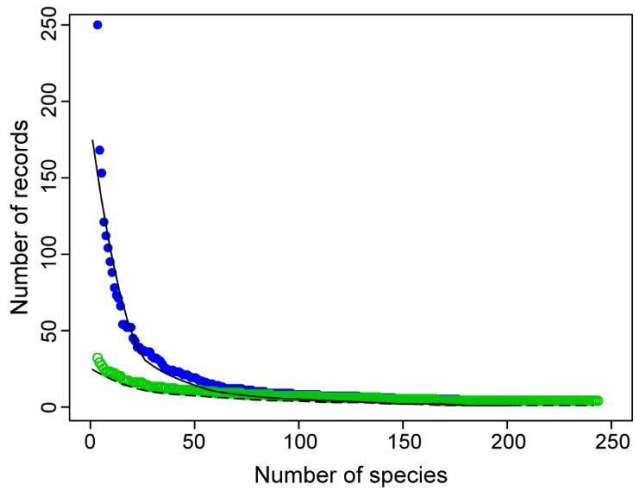
850 **Figure 1.** Distribution of records on the impact of IAPs in Italy *per* administrative region. A)
851 Distribution of records on impact mechanisms. B) Number of IAPs exerting any type of impact
852 mechanism. C) Distribution of records on impact outcomes on plant communities. D) Number of
853 N2000 Habitat types exposed to some degree of ecological impact by IAPs. E) Percentage of N2000
854 Habitats exposed to some degree of ecological impact by IAPs on the total number of Habitat
855 harboured in the region.



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858 **Figure 2.** Number of data collected regarding the presence of impact mechanism (empty green
859 circles, dashed line) and impact outcomes (full blue circles, solid line) exerted by IAPs in Italy.
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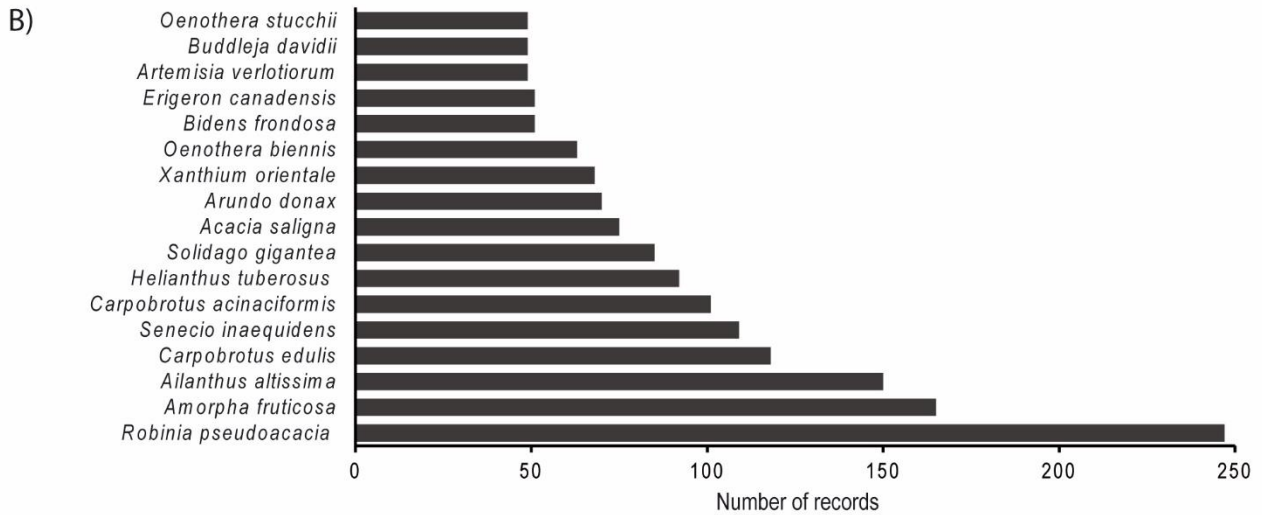
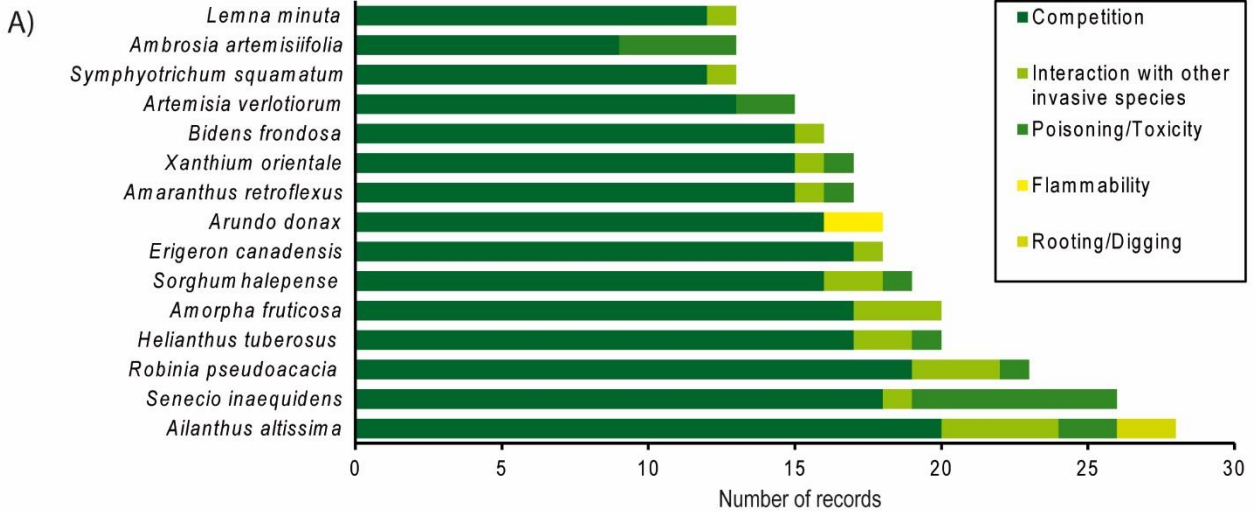
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Figure 3 A) Number of regional records with specific impact mechanisms for the first 23 IAPs. B) Number of total records of impact outcomes for the first 23 IAPs.

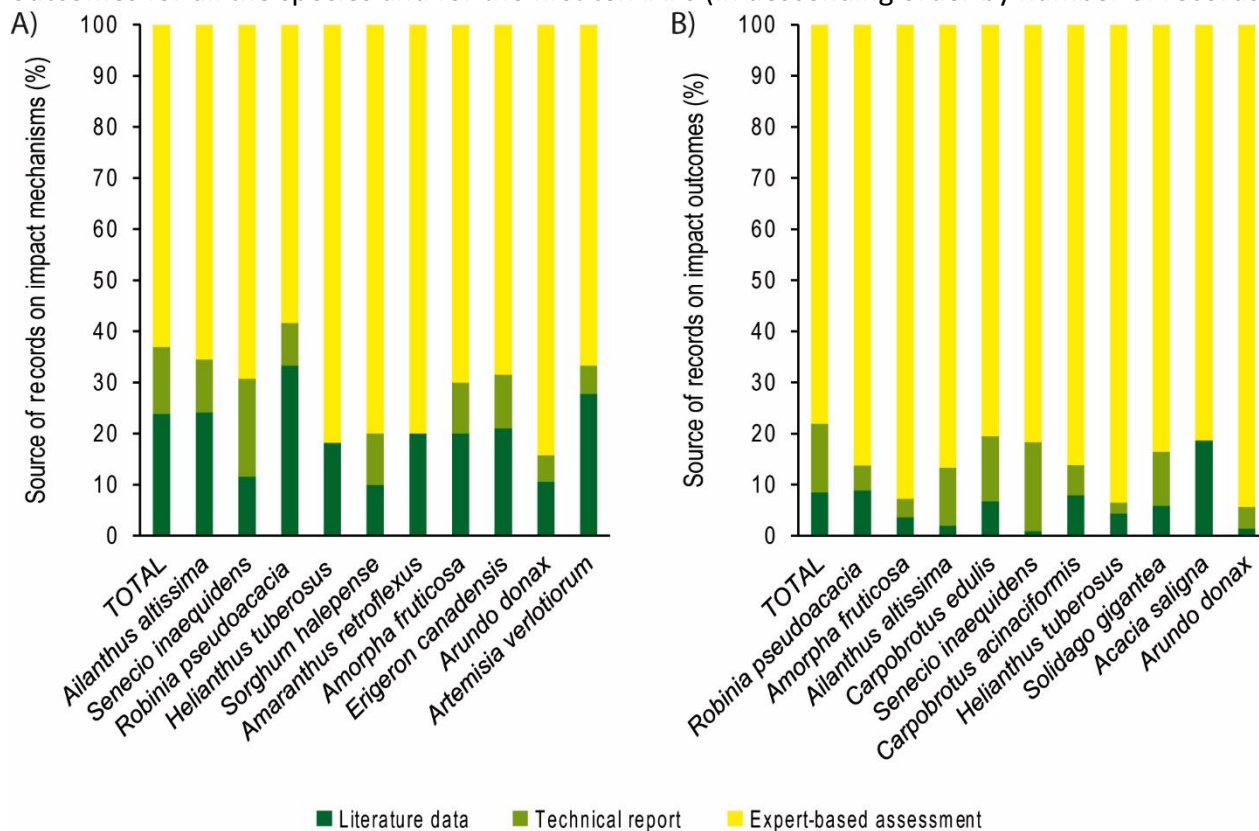


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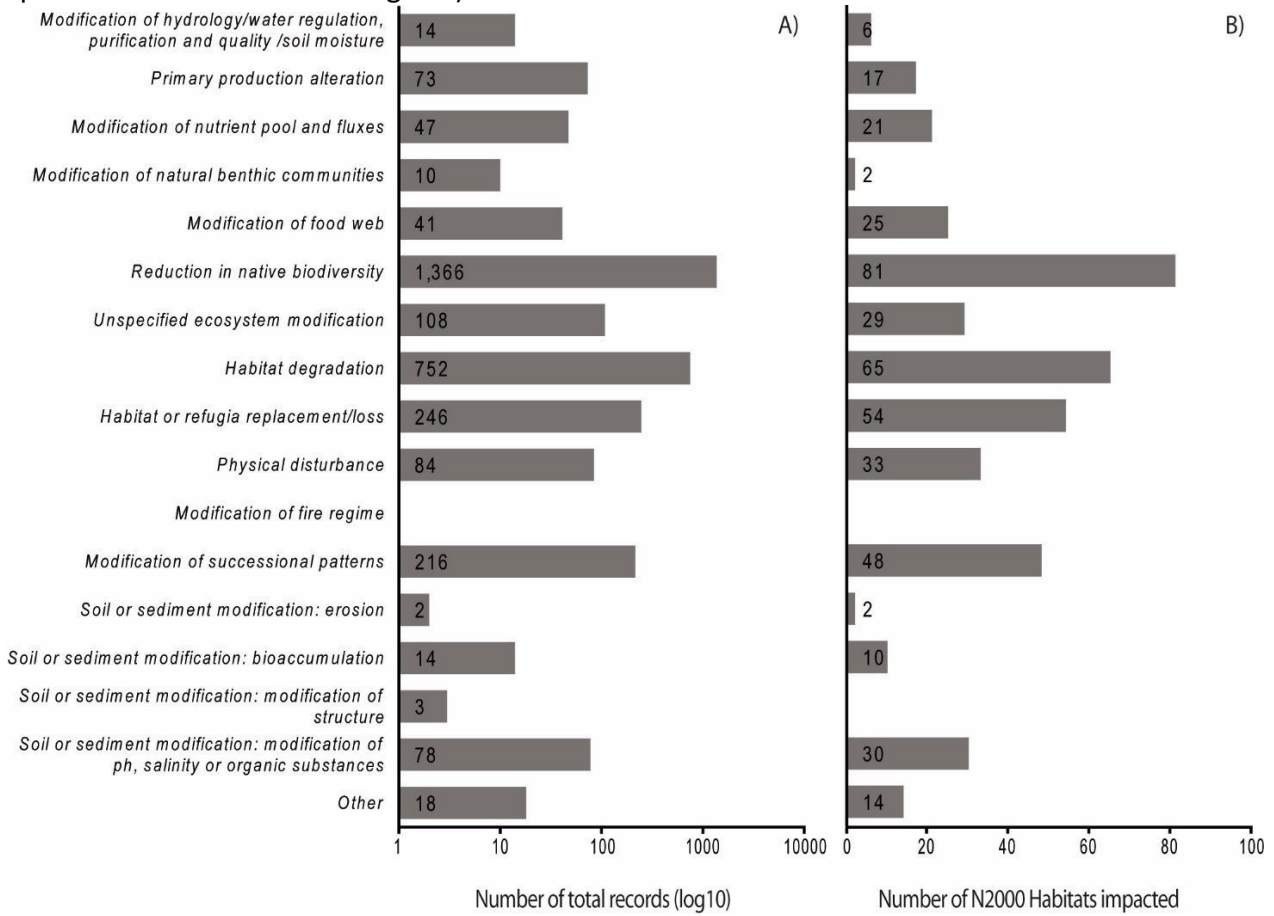
Figure 4. Source of the reports (in percentage) concerning A) impact mechanisms and B) impact outcomes for all the species and for the first ten IAPs (in descending order by number of records).



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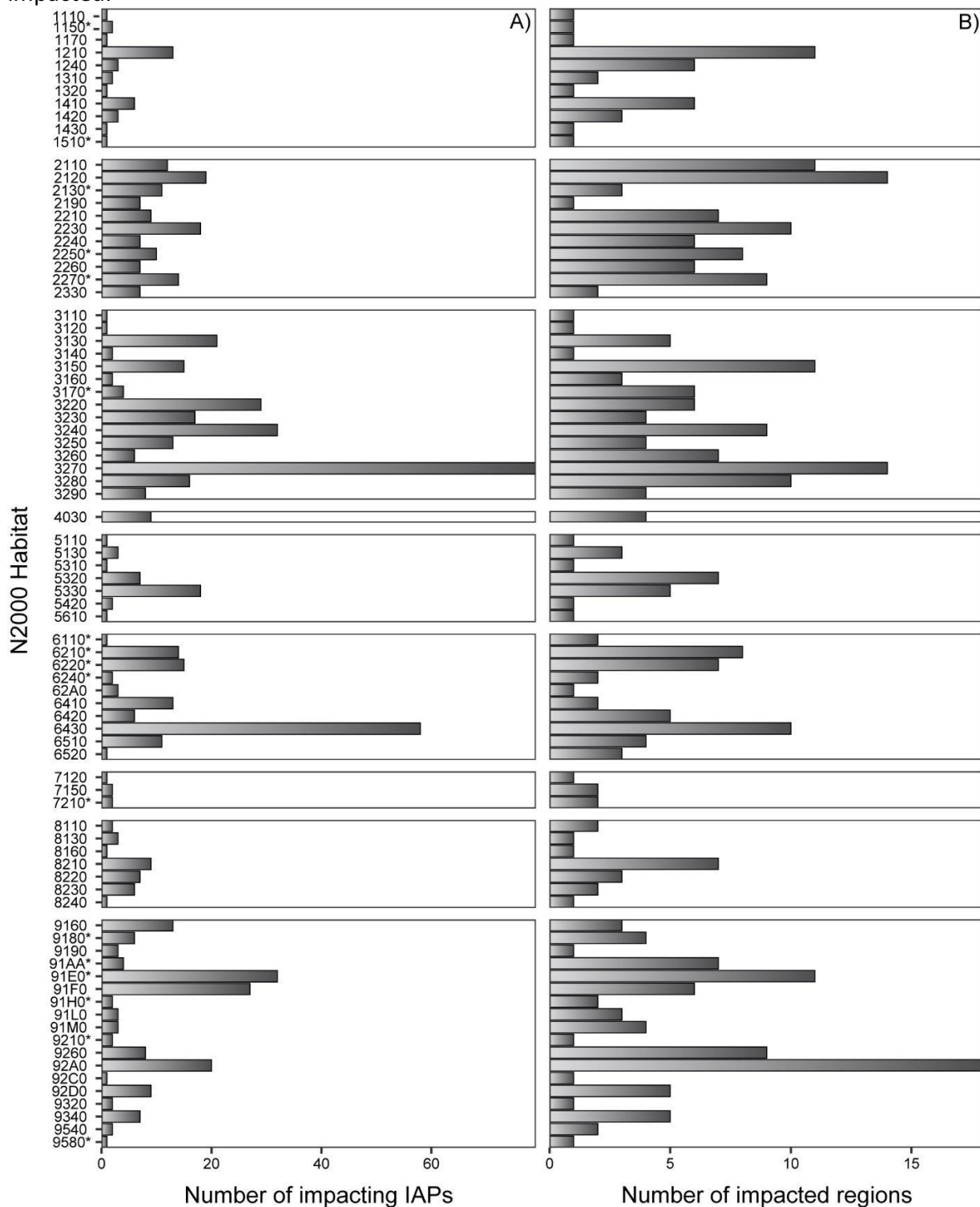
Figure 5. Impact outcomes. A) Total records (i.e. species × N2000 habitat × administrative region). B) Total number of N2000 Habitats suffering from a specific impact outcome (irrespective of species and administrative regions).



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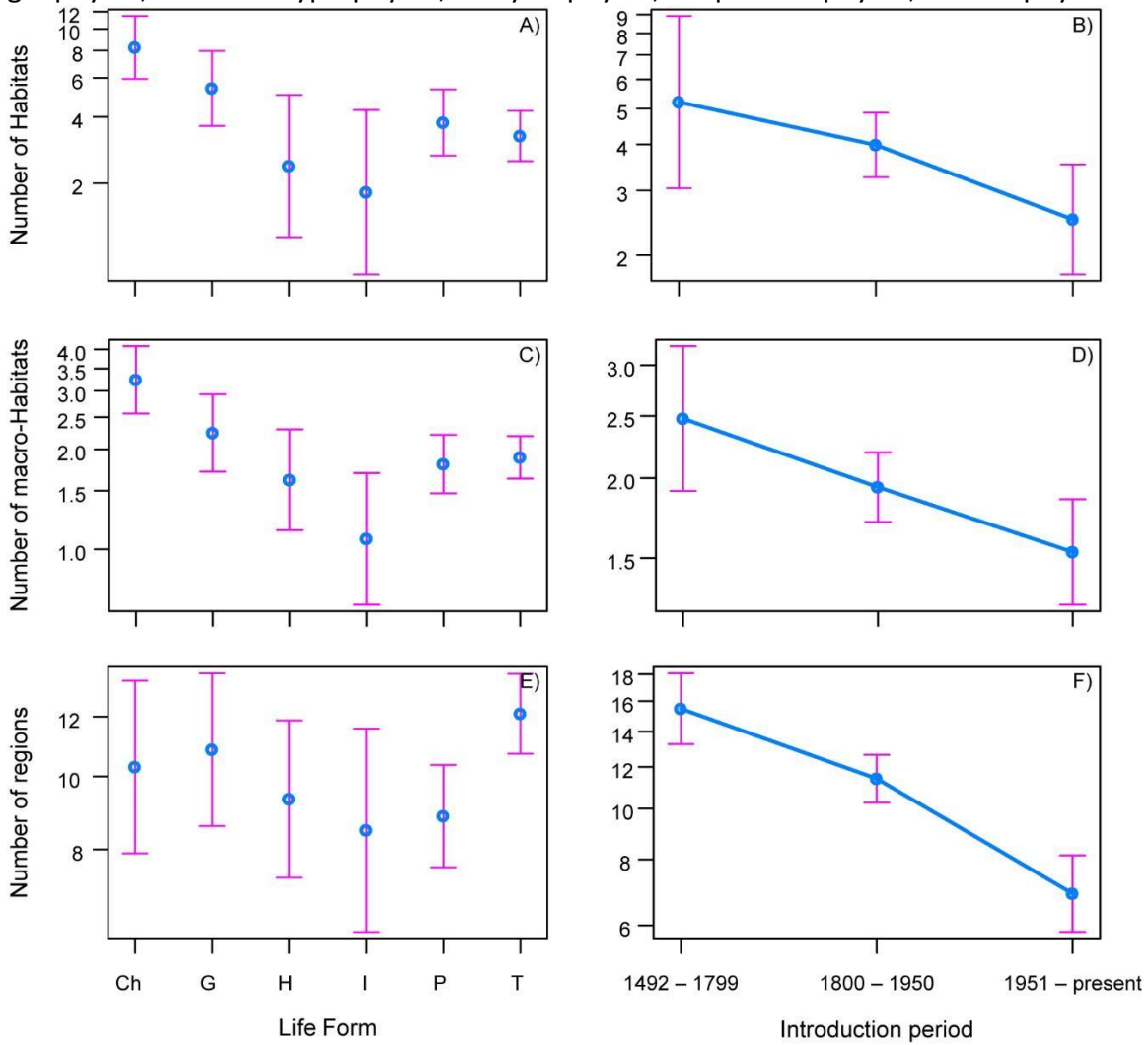
Figure 6. Data on the impact outcomes recorded per N2000 Habitat (*sensu* Habitat directive 92/43/EEC). A) Number of species exerting some degree of ecological impact for each target N2000 habitat and B) number of administrative regions in which the target N2000 habitat is impacted.



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887 **Figure 7.** Effect of the life form categories (A, C, E) and introduction period (B, D, F) on the number
888 of N2000 Habitats (Habitats), number of macro-categories of N2000 Habitats (Macro-habitats) and
889 the number of invaded administrative regions (regions), respectively. C = chamaephytes; G =
890 geophytes; H = hemicryptophytes; I = hydrophytes; P = phanerophytes; T = terophytes.



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