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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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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

The European Union Regulation no. 1143/2014 sets out the rules to tackle the adverse impacts of invasive alien species on biodiversity within the European Union. Aiming to promote an effective implementation of this legislation, the Italian Society of Vegetation Science carried out a large survey lead 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 and their outcomes on plant communities and on the EU habitats “worthy of conservation”, according to the Directive no. 92/43/EEC in Italy. A total of 241 alien plant species was assessed focusing on those known to have deleterious ecological impacts. The data collected allowed pinpointing the current state of the art, highlighting the main gaps of knowledge and indicating topics to be further investigated. Particularly, the survey underlined competition as the main ecological impact on plant communities and Natura 2000 Habitats. Among these 241 species, only *Ailanthus altissima* was assessed to exert ecological impacts on plant communities and Natura 2000 Habitats in all Italian regions; while a further 20 plant species were reported having impacts on up to ten out of the 20 Italian administrative regions. According to our data, 84 out of 132 Natura 2000 Habitats (63 %) are subject to some degree of impact by invasive alien plants. Forest were the most threatened habitats, followed by freshwater, marine coastal and dune and open grassland habitats. Although not exhaustive, this research represents the first example of evaluation of the ecological impacts of invasive alien plants on plant communities and EU Habitats carried out at the national level and considering multiple biogeographical and ecological scales.

Keywords :

Competition; Impact mechanism; Impact outcome; Natura 2000 network; Policy; Protected Areas

1. Introduction

Biological invasions are one of the most relevant drivers of biodiversity loss and ecosystems degradation globally (Seebens et al., 2017). The establishment and spread of invasive alien species (IASs) affect multiple ecosystem processes, including community composition, biotic interactions and functions and services (Vilà and Hulme, 2017). Furthermore, IASs can also harm relevant socio-economic assets, reducing the efficiency of natural resources exploitation, affecting infrastructure effectiveness, and imposing costly management efforts (Hoffmann and Broadhurst, 2016; Bacher et al., 2017).

Hence, understanding the predominant mechanisms underlying biological invasions is one of the most urgent and complex goal in conservation biology. The knowledge about this topic is crucial for predicting habitat invasibility (i.e. susceptibility to invasions) and recognizing the community responses to invasion in order to implement actions for the restoration and long term management of invaded habitats. Indeed, habitat invasibility may vary considerably depending on their biotic and abiotic characteristics, propagule pressure, and climatic factors (Chytrý et al. 2008) as well as on impact type. Across literature, human disturbance and fluctuating resource availability have been generally considered the main promoters of plant invasion across habitats (Inderjit 2005). However, despite this general awareness exhaustive works investigating the impact mechanisms of invasive alien plants on native plant communities and Natura 2000 (N2000) Habitats are still lacking.

In this regard, to oppose to the ever-increasing expansion of IASs and tackle their adverse manifold impacts, the European Union (EU) adopted the Regulation (EU) 1143/2014, subsequently transposed in Italy by the Legislative Decree no. 230/2017. Towards the national implementation of the EU Regulation, the Italian Institute for Environmental Protection and Research (ISPRA) has developed, among others, a project focusing on the collection of information regarding impacts of invasive alien plants (IAPs) on biodiversity and on N2000 network according to the Habitats Directive (Council Directive 92/43/EEC). The Italian Society of Vegetation Science (SISV) has in turn been actively involved in both: i) detailing the presence of alien-dominated plant communities (Viciani et al., in press); ii) providing an assessment of the ecological impacts of IAPs on N2000 Habitats in Italy, including information concerning the main impact mechanisms and outcomes, given at the local scale.

The N2000 network proved to be crucial for preserving the EU's biodiversity, even if there are increasing calls for improvement and adjustments (Ferreira and Beja, 2013; Trochet and Schmeller, 2013; Friedrichs et al., 2018). The importance of the N2000 network in tackling the risks posed by the biological invasions has been reinforced since 2011 by the European Commission, as stated in *The EU 2020 Biodiversity Strategy* (European Commission, 2011), and further strengthened by the recent EU 2030 Biodiversity Strategy mainly aimed at addressing the key drivers of biodiversity loss, including IAPs. However, while several EU member countries have updated their legislation and established action plans or practices to control and/or eradicate invasive species, a common approach is still missing, particularly for protecting the N2000 network. To date, the success

against or the vulnerability to invasive alien species of the N2000 network is in large part unknown (Guerra et al., 2018; Mazaris and Katsanevakis, 2018). According to Gallardo et al. (2017), protected areas and in particular N2000 network, seem to be a valuable tool to tackle invasive species spread also in the light of future climate change, even if human accessibility seriously undermines their effectiveness.

In Italy, the research on IAPs has gained momentum in the last 20 years (Lazzaro et al., 2019). Celesti-Grapow et al. (2009) published a first comprehensive and a new checklist of the vascular flora alien to Italy was lately published (Galasso et al., 2018a). Several projects and researches have been carried out in the last ten years at the national level (e.g. Malavasi et al., 2018; Celesti-Grapow et al., 2016; Lazzaro et al., 2019), but scientific literature concerning the impacts in Italy, especially on plant communities and on N2000 network is still uneven and suffers a gap in knowledge cover among taxa and N2000 habitats.

Toward the aim of effective implementation of legislation regarding the management of IAPs at the National scale, ISPRA coordinated a large survey, conducted by botanist members of SISV. The survey aimed to assess the impacts of IAPs on native plant communities and N2000 Habitats in Italy and include information concerning the main mechanisms and outcomes of impact, given at the local scale.

2. Methods

2.1 Definitions and context

General usage of terms linked to invasion biology follows mainly the key definitions in Blackburn et al. (2014). In accordance with Regulation (EU) 1143/2014 we defined an invasive alien species as “*an alien species whose introduction or spread has been found to threaten or adversely impact upon biodiversity and related ecosystem services*”. We focused on ecological impacts defined as “*a measurable change to the properties of an ecosystem by an alien species*”, considering only deleterious impacts, particularly intended as “*any impact that changes the environment in such a way as to reduce native biodiversity or alter ecosystem function to the detriment of the incumbent native species*” (Blackburn et al., 2014). We included both natural and semi-natural ecosystems, considering only impacts affecting the native biota and/or the ecosystem processes. Conversely, we did not consider in our survey any impact at the individual or population level on native species, nor any form of effect on the human society (thus excluding any economic/social and health effect of IAPs).

The data collection followed the Impact scheme of the Global Invasive Species Database (GISD 2020), as they are described in Blackburn et al. (2014). Particularly, we adopted all possible impact mechanisms identified by the scheme, and all the environmental impact outcomes at the ecosystem/habitat level (see Table 1).

Table 1. Impact mechanisms and outcomes adopted in the survey of Italian IAPs. Each mechanism in right column may results in one or more than one outcome in left column (Blackburn et al., 2014).

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

The nomenclature of IAPs follows Galasso et al. (2018a). As a pivotal part of our data collection was to assess the effect of IAPs on Habitats of European interest to define Habitat types, we followed the “Italian Interpretation Manual of the 92/43/EEC Directive Habitats” (Biondi et al., 2009) and the Interpretation manual of European Union EU28 (European Commission, 2013).

2.2 Survey strategy

Our evaluation of the current impact outcomes of IAPs in Italy was based on a survey of the literature and expert opinion from a large number of contributors, conducted through a voluntary call within all the SISV members. This resulted in the participation of 49 contributors (the coauthors of the present work – mainly technician or academic botanists, experts in vegetation science, N2000 Habitats and IAPs), providing data and their expertise at local level or regarding specific IAPs.

We conceived and provided each expert with a spreadsheet template including specific guidelines explaining the type of data required and how to fill the spreadsheet. The template included an initial list of 184 established IAPs for Italy directly derived from the data provided to ISPRA by the Italian Botanical Society within the National Alien Plant Species Data Base (Lazzaro et al., 2019). The contributors were asked to provide data on impact mechanisms and outcomes in their region according to Blackburn et al. (2014), see Table 1 . Particularly, for each species of the list, experts were asked to provide the following information: a) impact mechanism, b) impact outcomes, c) impact outcomes with specific reference to N2000 Habitats, d) data source, specifying whether it originated from i) scientific literature, ii) technical reports or grey literature, and iii) expert

assessment, and e) level of uncertainty of the data provided. In addition, contributors were encouraged to add any possible IAP not present in the list in case they assessed the presence of impacts.

The survey strategy adopted here followed the framework of the consensus building approach (see Vanderhoeven et al., 2017), in which several rounds of structured questionnaires, with subsequent aggregation of responses and feedbacks to the experts are used to reduce inconsistencies among assessors. In our case, in a first round of evaluation, the contributors were asked to fill individually the template provided, after reading the guidelines provided and the referenced documentation. After this preliminary data collection (ended on 2017 July 31), the information collected were aggregated and showed to all the 49 contributors during a two-day workshop (2017 October 16-17), to discuss possible shortcomings, identify possible gaps in the knowledge and uniformity in the data collection. After the workshop, we opened a second call (conclusion in 2017 December) to allow all the contributors to homogenize the data provided and fill shortcomings emerged during the workshop.

2.3 Data analyses

2.3.1 Breakdown of results on IAPs and impacts outcomes and mechanisms

All the collected information on the impacts (mechanisms and outcomes) on plant communities and on N2000 Habitat was merged in a single database that was subsequently cleaned and standardized adjusting possible syntax errors and deleting duplicate records. Information was provided for general impacts on the native plant communities, with special emphasis on N2000 Habitat. A general breakdown of the data collected assessing the distribution of records on the impact of IAPs on the native communities, as well as information on the type of impact and their outcome was provided for species and administrative region .

2.3.2 Patterns of invasion on N2000 Habitats

We provided more detailed analyses on IAPs having an impact outcome on the N2000 Habitats at the national level, to assess the presence of specific trends of invasion. Thus, for these species we collected data regarding the life form, the number of administrative regions colonized (according to Galasso et al., 2018a and subsequent updates, Galasso et al., 2018b; 2018c) and the date of the first introduction in Italy searching in the literature and technical sources (see Appendix 2). This information is very uneven between species because it can correspond to either the date of the first introduction in botanical gardens or the first detection in nature, thus being largely unreliable. Accordingly, we chose to reclassify neophytes in three main groups: 1) introduced between 1492 and 1800, 2) introduced between 1800 and 1950 and 3) introduced from 1950 to date 2020). This grouping (hereafter named introduction period) reflects the main changes in global dimension of human flows, passing from the age

of geographical discoveries to the XIX century (1492–1799), from the colonialism to the industrial revolution and to the two world wars (1800–1950), and finally from the time of economic boom to globalization (1951–2020).

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

We analyzed the impacts on N2000 Habitats at the finest level (indicated by the entire N2000 code, e.g. 1210) and grouped per macro-categories indicated by the first number of the N2000 code (e.g. 1: coastal habitats, 2: dune habitats and so on; see European Commission, 2013). Data were merged at the national level with the aim of avoiding possible biases linked to differences in the number of Habitat types that the different administrative regions naturally harbor.

To investigate the correlation between the number of Habitats, number of macro-categories of Habitats and the number of administrative regions colonized, we ran a correlation analysis for each introduction period, evaluating the pairwise Spearman's rank correlation coefficient (Spearman's ρ) and its significance via the asymptotic t approximation.

Finally, we run a series of Generalized Linear Models (GLM) studying the effect of the introduction period and the life form categories on the number of N2000 Habitats, the number of macro-categories of invaded N2000 Habitats and the number of invaded administrative regions. Given the overdispersion of our data, we adopted a quasi-Poisson distribution and evaluated the significance of the terms with an ANOVA table. All the analyses were conducted in R environment vers. 3.6.1 (R Core Team 2019).

3. Results

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

We collected data on 241 IAPs, 57 more than the 184 originally indicated in the template (see Appendix 2). Only a few of them were reported in a high number of administrative regions and by several contributors. In general, the degree of knowledge varied strongly among regions, as shown by the different numbers of regional records regarding impact mechanisms and outcomes (Figs. 1A and 1B). In addition, the number of IAPs with some degree of ecological impact widely varies among administrative regions (Fig. 1C), as well as the distribution of impacts on N2000 Habitats (Fig. 1D).

Records were also strongly uneven concerning which species exert any impact outcome and through which mechanism. Indeed, most IAPs had very few reports of mechanisms of impact (i.e. 220 out of 241 species had less than five reports of impacts in different regions), while very few species had a high number of records. Also

concerning impact outcomes on native plant communities, most of the species had very few reports and very few species had a high number of records (see Fig. 2).

Among others, “*Competition*” was the most frequent impact mechanism, being common to around 83% of total reports, followed by “*Unknown*” mechanism (4%), “*Interaction with other invasive species*” (4%) and “*Poisoning/toxicity*” (3%).

Ailanthus altissima, listed in all the 20 Italian administrative regions, was the species with the highest number of records of impact mechanisms, mostly exerting impacts via competition, but also “*Rooting/digging*” was a significant mechanism. Further species with a very high number of records, as *Senecio inaequidens*, *Robinia pseudoacacia*, *Helianthus tuberosus* and *Sorghum halepense*, were all assessed as invaders with a high degree of impact in many administrative regions (see Fig 3A for main mechanisms of the first 23 species). Nevertheless, also in the case of species with a high number of impact reports, most data were provided basing on expert-based assessments that were not experimentally verified (Fig. 4 A). Only 25% of the reports were derived from the scientific literature, 13% from technical reports and grey literature and 62% were derived from expert-based assessments.

We detected some important changes as to the identity of species with the highest numbers of impact outcomes, compared to the data on impact mechanisms. *Robinia pseudoacacia* was the species with the highest number of records, followed by *Acacia saligna*, *Amorpha fruticosa*, *Arundo donax*, *Ailanthus altissima*, *Carpobrotus edulis*, *C. acinaciformis*, *Helianthus tuberosus*, *Senecio inaequidens*, and *Solidago gigantea* (Fig 3B). Again, most of these records (78%) were derived from expert-based assessments, while 13% of them came from technical reports and grey literature and only 9% from scientific literature (Fig. 4B).

Reduction in native biodiversity was by far the most represented outcome, followed by general habitat degradation, loss of habitat and refugia, and modification of successional patterns (Fig. 5A). These numbers are reflected also in the threats posed to N2000 Habitats. Indeed, the reduction in native biodiversity was cited approximately for all N2000 Habitats present in Italy (81 out of 84), followed by the same outcomes named above (Fig. 5B).

Nonetheless, the presence of impacts on the Habitats had an uneven distribution, especially concerning the number of IAPs impacting specific habitats, and less concerning the number of regions in which each Habitat has been assessed as being subjected to some degree of impact (Fig. 6A-B). N2000 Habitat 3270 (Rivers with muddy banks with *Chenopodium rubri* p.p. and *Bidention* p.p. vegetation) was by far the one impacted by the highest number of invasive species (i.e. 79 species), followed by N2000 Habitat 6430 (Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels). The freshwater habitats (N2000 Habitats 3xxx) and natural and semi-natural grassland formations (N2000 Habitats 6xxx) were impacted by the highest number of alien species, followed by coastal sand dunes and inland dunes (N2000 Habitats 2xxx) and forests (N2000 Habitats 9xxx). When looking at the regional distribution of impacted habitats the freshwater habitats

were generally affected in many regions, with also coastal sand dunes, coastal and halophytic habitats (N2000 Habitats 1xxx) and forests gaining importance (Fig 6 B).

3.2 Patterns of invasion on N2000 Habitats

The 241 IAPs recorded in our survey included 167 neophytes invading the EU Habitats; 29 of them have been introduced before 1800, 84 between 1800 and 1950 and 54 after 1950 (Appendix 2). Therophytes (56 species) and phanerophytes (45) comprised the majority of the records, followed by hemicryptophytes (19), geophytes (17), chamaephytes (16) and hydrophytes (14). *Ailanthus altissima*, *Robinia pseudoacacia*, *Senecio inaequidens*, *Amorpha fruticosa*, *Carpobrotus edulis* were the most frequent invaders in both N2000 Habitats (28, 25, 23, 17, 16 each respectively) and macro-categories of habitats (7, 7, 8, 6, 5 respectively) even with slightly different rankings (see Appendix 2). The number of Habitats and of macro-categories of Habitats colonized were resulted highly correlated for the species introduced in all three periods (p value < 0.001 , see Table 2), although with values slightly decreasing from those of the species introduced before 1800 ($\rho = 0.930$) to those introduced from 1950 to date ($\rho = 0.845$). Conversely, only for the species introduced before 1800 the number of regions colonized was resulted significantly correlated with the number of Habitats ($\rho = 0.523$, p value = 0.003) and of the macro-categories of Habitats ($\rho = 0.489$, p value = 0.007), while no significant correlation was recorded in the other two periods (Table 2).

Life form categories significantly affected the distribution of species in terms of the number of invaded N2000 Habitats (and of macro-categories of habitats), as well as in terms of administrative regions invaded (Table 3). Generally, chamaephytes invaded more habitats (and macro-categories of habitats), followed by geophytes, phanerophytes and therophytes, while hydrophytes were specific to a small number of habitats (Figs. 7A, C). In turn, therophytes spread in the highest number of regions, together with geophytes (Fig. 7E). In addition, the introduction period highly affected the number of habitats (and of macro-categories of habitats), as well as the number of administrative regions invaded (Table 3). Indeed, the longer a species has been introduced, the higher the number of habitats, macro-categories of habitats and administrative regions invaded (7 B, D, F).

Table 2 Correlation matrices between the number of N2000 habitats (Habitats), number of macro-categories of N2000 habitats (Macro-habitats) and number of invaded administrative regions (Regions), for each introduction period. In each correlation matrix, upper triangle (numbers in plain text) displays the value of Spearman's rank correlation coefficient (Spearman's rho), while lower triangle (numbers in italic) displays its significance.

Introduction Period		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>	-

Table 3 Analysis of the deviance table for the generalized linear models studying the effect of life form categories and introduction period on the number of N2000 habitats (Habitats), number of macro-categories of N2000 habitat (Macro-habitats) and number of invaded administrative regions (Regions). χ^2 = Likelihood ratio Chi-square; Df = Degree of freedom; 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
	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
	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
	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 been still only partially unraveled at the national level. Only very few data on the impact mechanisms exerted by IAPs are available, greatly reducing our ability to implement effective adaptive strategies in order to counteract the IAPs’ spreading and effects. Additionally, data have a strong uneven distribution across regions, further reducing our capacity to understand the nation-wide effects of IAPs. This urgently calls for a nation-wide collaborative initiative to fill these knowledge gaps and adopt coordinated action programs.

The differences in recorded impacts among Italian regions is consistent with the findings of the main catalogues of alien plants in Italy (Galasso et al., 2018a; Celesti-Grapow et al., 2009). Indeed the highest number of records

is generally observed in the largest, most densely populated and most/or more industrialized regions, as well as devoted to intensive agriculture (i.e. Lombardy, Piedmont, and Tuscany) though some large regions showed a net opposite trend (e.g. Lazio, Emilia-Romagna). This difference in regional records is probably the results of (at least) two factors. On the one hand, more densely populated and more industrialized regions are more likely to be subject to a higher rate of introduction (Dodd et al., 2015; McLean et al., 2017). In many cases, the intensification of agricultural land use plays a crucial role in the introduction, establishment and spread of IAPs linked to a biodiversity decline by oversimplifying landscape matrices (Walker et al., 2009; Tschardt et al., 2005). This is especially true for lowland riverscapes due to the deterioration of water, sediments and hydrological regimes (Bolpagni and Piotti, 2015; Bolpagni et al., 2013), features that again tally with the key role they play as the most common ways of establishment and spread of IAPS in newly invaded areas (Aronson et al., 2017).

On the other hand, there are different levels of awareness in the different administrative regions in Italy. A number of regions already adopted specific regulatory frameworks addressing the issue of biological invasions (Brundu et al., 2020), while other regions still pay little attention to this matter. Only Lombardy, Piedmont, Aosta Valley have a black list of IAPs approved by regional laws and working groups dedicated to IAPs. In Friuli-Venezia Giulia and Tuscany only few IAPs are taken into account in regional laws. Finally, Liguria has 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 are lacking a regulatory framework on IAS, even if the recent promulgation of legislative decree no. 230/2017 calls for a comprehensive framework to tackle this issue. The high number of expert-based assessments in our survey underscores the major difficulty in retrieving suitable and reliable literature on the impacts of IAPs in Italy. Indeed, also for very well-studied species, generally considered “*a priori*” as a serious threat to biodiversity, direct evidence is frequently lacking. The knowledge gap among taxa is a well-known issue linked to the study (and management) of the impacts associated to biological invasions, with most papers on impacts focusing on a narrow set of well-studied species, as already raised in the literature (Hulme et al., 2013). This is especially relevant when considering that all data concerning impacts represent a valuable source of information necessary to lay the basis for any generalization about biological invasions and are useful for risk assessment and management (Bolpagni et al., 2014a; Lazzaro et al., 2015).

For example, the information concerning *Ailanthus altissima* comes mainly from regional reports and checklists, often lacking a direct measurement of the cited impacts (see Badalamenti et al., 2016; Maiorca et al., 2007). Even if the impacts caused by this species are relative well-studied (Castro-Díez et al., 2019), impacts in Italy are only documented for Sardinia (Traveset et al., 2008; Vilà et al., 2006) and the Karst area, North-East Italy (Uboni et al., 2019) and very little literature is linked to the impacts outcomes on plant communities or N2000 Habitats. Among the most studied species *Robinia pseudoacacia* stands out as a major invasive tree in Europe (Kleinbauer et al., 2010; Vítková et al., 2017). Many studies in Italy focused on the impacts of this species

(Nascimbene et al., 2012, 2015; Benesperi et al., 2012; Lazzaro et al., 2018; Sitzia et al., 2018; Campagnaro et al., 2018; Gentili et al., 2019). Some authors found evidence that the rapid expansion of this species in Italy is causing a progressive decline of native forests, with loss of species richness and diversity and a shift in species composition towards nitrophilous plants (Benesperi et al., 2012; Lazzaro et al., 2018; Allegrezza et al., 2019). Conversely, other authors showed that secondary *Robinia* forests, growing on abandoned lands, may host compositionally heterogeneous plant communities and may contribute to some degree to regional biodiversity (Campagnaro et al., 2018). Nevertheless, it is noteworthy that, as pointed out also by Lazzaro et al. (2018), *Robinia* forests in many cases replace habitats considered worthy of conservation in Europe (i.e. N2000 Habitats 9260, 91B0, 91M0, 91AA* (Montecchiari et al., 2020) and 92A0 among others).

Among highly invasive tree species, *Prunus serotina* and *Quercus rubra* have also been reported to greatly impact native communities (i.e. *Carpinus betulus*-*Quercus* spp. forests) and ecosystem components at the soil level, mostly in Northern Italy (Gentili et al., 2019; Vegini et al., 2020). *Acacia* is another well-studied genus in Italy, in accordance with general global trends. The negative impacts on plant communities due to the invasion of these nitrogen-fixing trees have been well documented for different species (e.g., *A. dealbata*: Lazzaro et al., 2014; Minuto et al., 2020; *A. pycnantha*: Lazzaro et al., 2015). Similarly, impacts on coastal dune N2000 habitats of *A. saligna* and *A. cyanophylla* are well-documented (Del Vecchio et al., 2013; Bonari et al., 2017; Calabrese et al., 2017).

Carpobrotus acinaciformis, *C. edulis* and their hybrids (Campoy et al., 2018) represent another well-studied group of invasive species, whose impacts on plant communities have been widely investigated in Italy. The negative effects of these species are well depicted on both biodiversity (Santoro et al., 2012; Jucker et al., 2013) and soil conditions (Zedda et al., 2010; Badalamenti et al., 2016; Santoro et al., 2011). Additionally, these species were largely investigated to assess the pattern of occurrence at the community level (Carboni et al., 2010; Sperandii et al., 2017) as well as the habitat preference, including N2000 Habitats 2120, 2210 and 2250* (Sarmati et al., 2019).

Some specific studies focused on the impact of different IAPs (e.g. *Ambrosia psilostachya*, *Cenchrus longispinus*, *Erigeron canadensis*, *Oenothera stucchii*, *Senecio inaequidens*) on sand dune ecosystems in north-eastern Italy, evidencing significant negative effects on species richness, species diversity and evenness, and plant community composition, with effects increasing from Habitats of the drift line (1210) to fixed-dune habitats (2130) (Del Vecchio et al., 2015).

Unfortunately, once these few well-studied IAPs are excluded, most of the records of impact on plant communities and N2000 Habitats collected in the present general assessment derive from expert-based evaluations. This applies in particular to the species listed among Invasive Alien plant Species of Union Concern [*sensu* Regulation (EU) no. 1143/2014], both because some of them are present in the Italian territory in a scattered or localized way (e.g. *Alternanthera philoxeroides*, *Pontederia crassipes*) and especially because, data on their impacts are still missing (with only a few exception; see e.g. Lastrucci et al. (2017) for *Myriophyllum*

aquaticum). The lack of information may also be due to the difficulty in obtaining reliable data for plants and vegetation in aquatic ecosystems, normally extremely time- and money-consuming to sample (Azzella et al., 2017). Indeed, half of the IAPs of Union concern are aquatic or wetland plants (19 out of 36), which confirms the bad general state of conservation of inland waters (Brundu, 2014; Lastrucci et al., 2017). Despite this, aquatic IAPs are generally neglected and little investigated in Italy so far. Evidence on their pivotal role in reducing local biodiversity has been collected for a series of deep subalpine lakes in Northern Italy (Bolpagni, 2013a; 2013b; Bolpagni et al., 2017). Here, *Lagarosiphon major* and *Elodea nuttallii* create extensive submerged meadows replacing almost completely the native macrophyte communities that belong to the N2000 Habitats 3140 and 3150. Furthermore, some investigations have been carried out to evaluate the ecosystem impacts and eco-physiological features of *Nelumbo nucifera* and *Ludwigia hexapetala* via remote sensing techniques in the context of Mantua lakes (Bolpagni et al., 2014b; Villa et al., 2017; 2018; Tóth et al., 2019). These two species seem to actively compete with the native ones due the enhanced competitive ability for limiting resources and tolerance to edaphic conditions variability (Tóth et al., 2019). Additionally, some specific studies focused on the impact of *Lemna minuta* on freshwater ecosystems of Central Italy, highlighting relevant negative effects on water quality, aquatic plant and animal communities (Ceschin et al., 2019; 2020). *Lemna minuta* has proven to cause drastic alterations of the local vegetation, often replacing native species, such as the most common duckweed *Lemna minor* (Ceschin et al., 2016a), assimilating the available nutrients faster and showing a higher relative growth rate (Ceschin et al., 2016b), characteristics that make this species highly competitive. However, for the majority of aquatic IAPs, the knowledge level is too scarce for the correct assessment of both the ecosystem impacts and the actions to carry out for an effective recovery of impacted ecosystems.

The survey also evidenced a group of well-known and widespread invasive herbs (i.e., *Amaranthus retroflexus*, *Ambrosia artemisiifolia*, *Artemisia verlotiorum*, *Bidens frondosa*, *Erigeron canadensis*), that are very competitive in disturbed habitats (agricultural areas, roadsides, ruderal areas) also thanks to their propagule pressure. Noteworthy is the presence of *Phytolacca americana* and *Solanum chenopodioides* in an old-growth *Quercus ilex* urban forest disturbed by a severe windstorm in Southern Italy (Bonanomi et al., 2018). However, the invasiveness of such species may change during different successional stages (Domènech and Vilà, 2006). For instance, the annual *Ambrosia artemisiifolia* is completely suppressed by late colonists and perennial species after a three-year succession (Gentili et al., 2017). Conversely, the invasion of *Solidago canadensis* has been reported to modify the trajectory of vegetation succession and to exert a higher negative effect on native diversity in older successional communities (Fenesi et al., 2015a; 2015b).

This survey highlighted that the elapsed time since the introduction affected highly significantly the number of Habitats colonized. Therefore, species of relatively recent introduction, not yet truly invasive, but with considerable potential in this regard, for the size of the introduced populations, should be better investigated. These include some species of *Eucalyptus*, especially *E. camaldulensis*, which in recent years show growing capacity to spread in river habitats of Sicily (Badalamenti et al., 2018). In this, as in other cases, biological

evolution acts on the introduced species and may enable some alien plants to occupy a broad range of novel habitats until they become invasive (Oduor et al., 2016). Tree species should be carefully monitored because although they take time to become invasive, when they do, their impacts are high because of their large biomass.

5. Conclusions

Our survey represents the first attempt to assess the impact of the most harmful IAPs on plant communities and habitats in Italy. The work highlighted a series of knowledge gaps on the impacts of IAPs on biodiversity in Italy, which corresponds with the classical gaps of plant invasion science at the global level (Packer et al., 2016; Latombe et al., 2017). The differences in knowledge among the Italian administrative regions may be linked to a general dissimilarity in awareness as shown by the differences in local policies and legal and management tools. Thus, a primary scope of the scientific community should be to level up at the national scale this unevenness. Again, in accordance with a general trend, we highlighted a general lack of experimental data, also for well-known invasive species. This is of primary importance to depict without knowledge bias the effective potential of impact of each single species, to both provide data for risk analysis and support and guide decisions at the political level. As to N2000 network, there is a lack of data also on the impacts on N2000 habitats, which should represent a primary focus for the conservation efforts. However, a coordinating strategy to evaluate and manage the risk of invasion at the Italian national level in the N2000 network is desirable.

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Author contributions

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

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FIGURES

Figure 1. Distribution of reports on the impact of IAP species in Italy *per* administrative region. A) Distribution of records on impact mechanisms. B) Number of IAPs species exerting any type of impact mechanism. C) Distribution of records on impact outcomes on plant communities. D) Number of N2000 Habitat types exposed to some degree of ecological impact by IAP species.

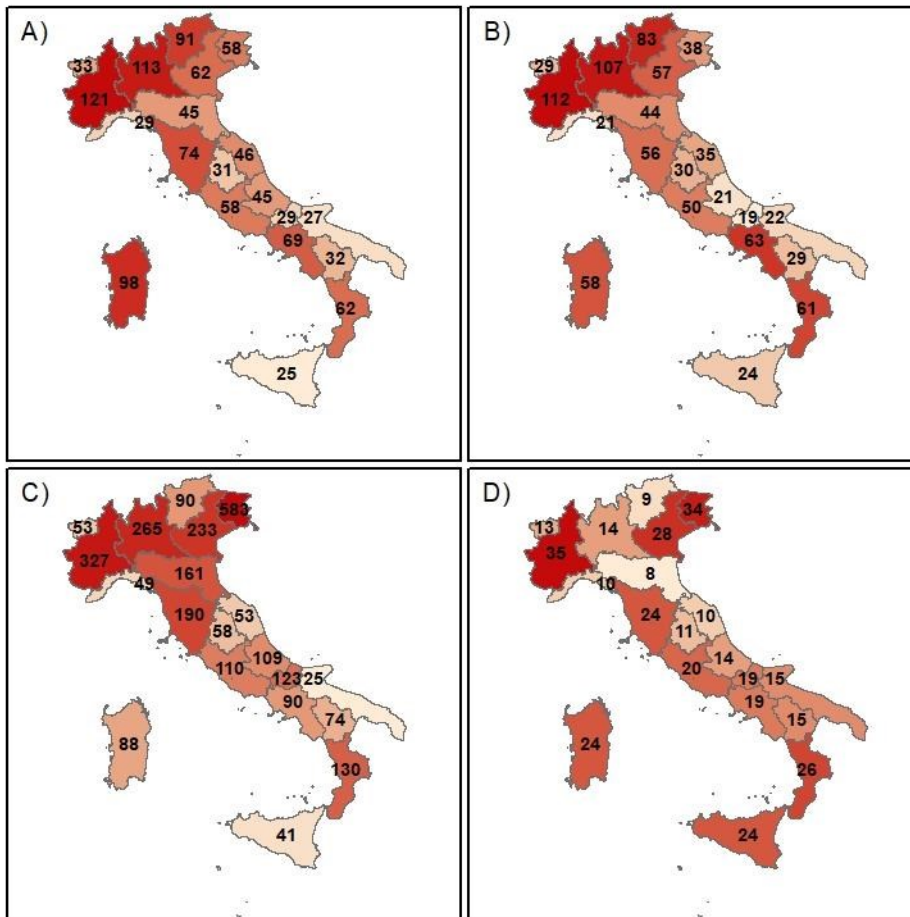


Figure 2. Number of data collected regarding the presence of impact mechanism (empty green circles, dashed line) and of impact outcomes (full blue circles, solid line) exerted by IAPs in Italy.

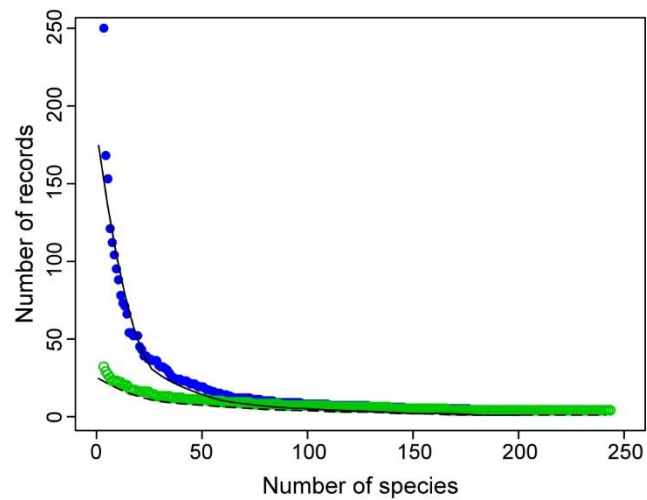


Figure 3 A) Number of regional records with specific impact mechanisms for the first 23 IAPs. B) Number of total records of impact outcomes for the first 23 IAPs.

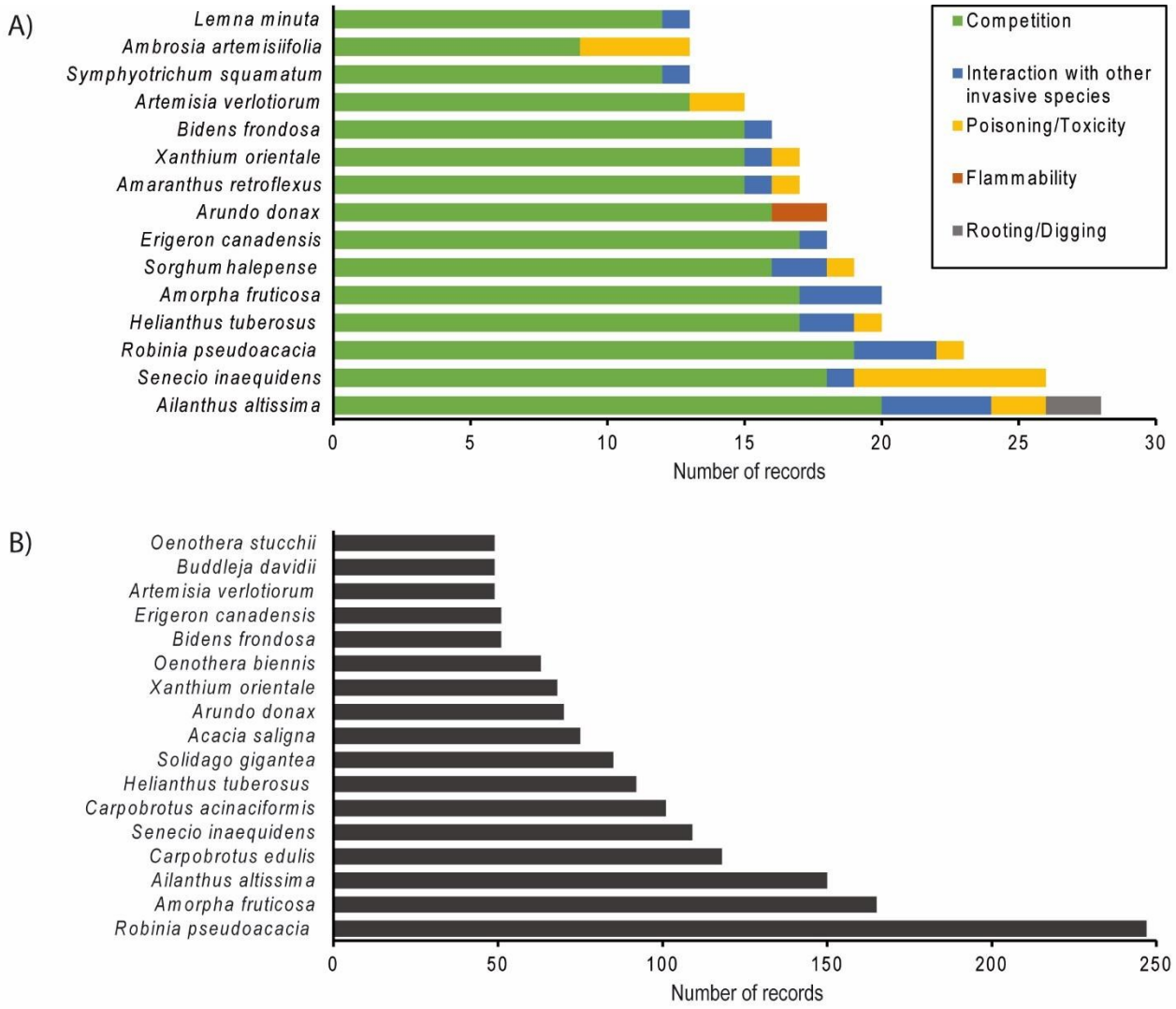


Figure 4. Source of the reports (in percentage) concerning A) impact mechanisms and B) impact outcomes for all the species and for the first ten IAPs (ordered by number of records from higher to lower).

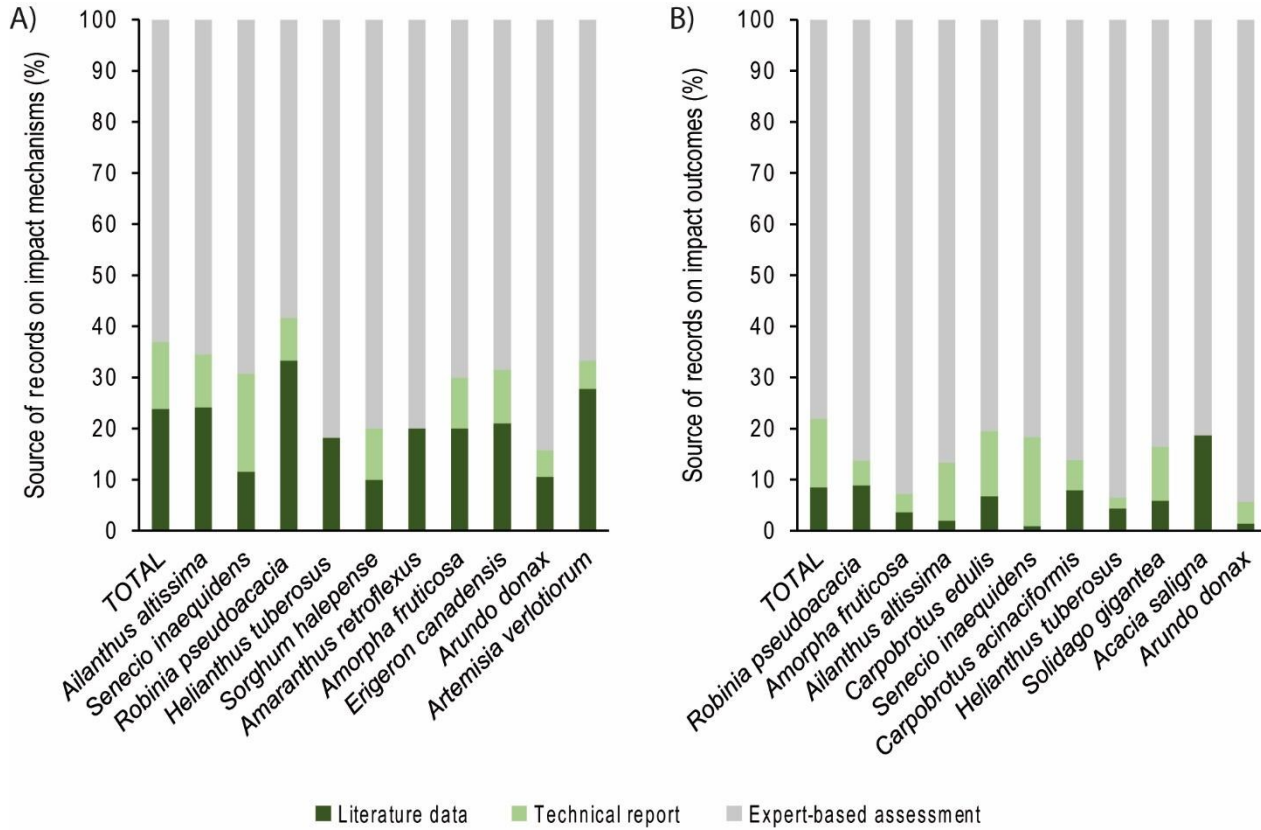


Figure 5. Impact outcomes. A) Total records (i.e. species × N2000 habitat × administrative region). B) Total number of N2000 Habitats suffering from specific impact outcomes (disregarding species and administrative regions).

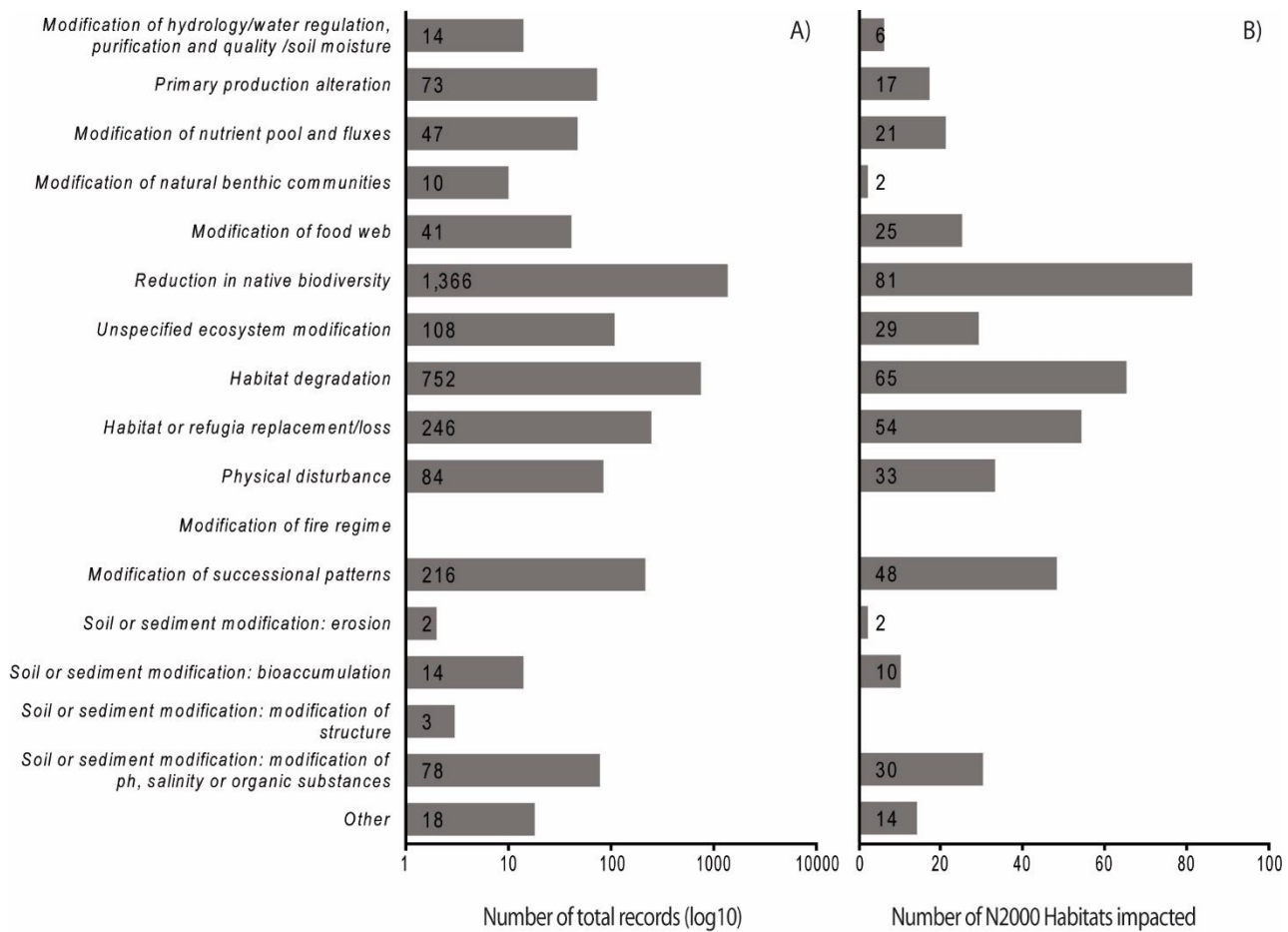


Figure 6. Data on the impact outcomes recorded per habitat type (*sensu* Habitat directive 92/43/EEC). A) Number of species exerting some degree of impact for each target N2000 habitat and B) number of administrative regions in which the target N2000 Habitat is impacted.

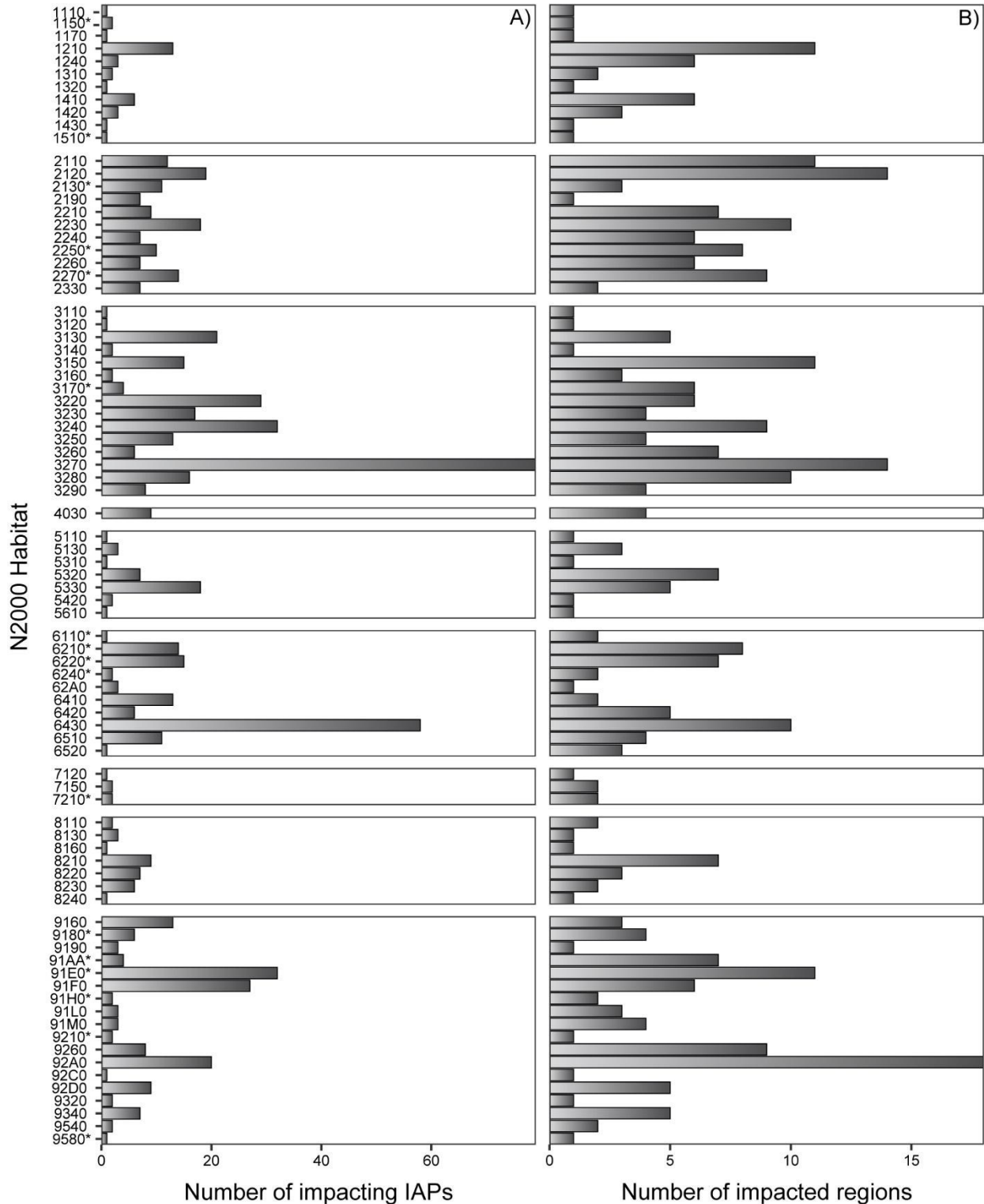


Figure 7. Effect of the life form categories (A, C, E) and introduction period (B, D; F) on number of N2000 Habitats (Habitats), number of macro-categories of N2000 Habitats (macro-habitats) and number of invaded administrative regions (regions), respectively. C = chamaephytes; G = geophytes; H = hemicryptophytes;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

