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ORIGINAL ARTICLE

Monitoring invasive alien plants dynamics: application in restored areas

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Abstract

In environmental restoration, evaluating the effect of control actions on alien species is essential for a correct assessment of the success of the restoration. A simple method for the evaluation of the dynamics of alien plants after manual and mechanical control in restored areas is proposed in this work. This method is based on the cover-abundance of alien plants, the size of the inventoried area and subsequently corrected with the degree of invasiveness based on national catalogues. Alien plants data abundances are obtained from floristic relevés retrieved from the restoration actions, carried out in the Eo River (Spain) during the LIFE Fluvial project (2018–2021). The Invasive Alien Plants Index (IAPI) was calculated, before and after the control actions for three ecological units (fluvio-estuarine, riverbank and lake). In all cases, index decreases after the control actions and it is sensitive to the changes that may occurs as recolonization by new alien species. As a whole, in the Eo River, a decrease of 53% of the IAPI has been obtained from 2018 to 2021, which estimate the effect of alien plants control. This indicator is applicable to any type of habitat, ecosystem or region and is adapted to different administrative areas that have published an official list of invasive species.

Keywords Biological invasions · Environmental restoration · Floristic relevés · Invasive alien plants index · Invasive species · Alien plants control

Introduction

The restoration of native ecosystems is an effective practice to increase biodiversity and improve associated ecosystem services, especially when acting in environments degraded by human activities (Benayas et al. 2009). In recent decades, large capitals have been invested in restoration projects, of which more than 80% are focused on biodiversity conservation (UNEP-WCMC et al. 2020). Invasive Alien Species (IAS) represent a significant threat to the receiving environments (Jeschke et al. 2014; Roiloa et al. 2020) and are one of the main causes of biodiversity loss (Gurevitch and Padilla 2004; McGeoch et al. 2010). They cause significant impacts at the species, community, and ecosystem level and often represent an economic and social problem (Charles and Dukes 2006; McGeoch et al. 2010), although, the magnitude of the impact is highly variable and context-dependent (Vilà et al. 2011). IAS control is an important task for the conservation and management of natural ecosystems, nevertheless, the characteristics of IAS removed, the degree to which they have supplanted native taxa, and the occurrence of other IAS can affect the impacts of control actions (Zavaleta et al. 2001). A major group of alien species reported in Europe are plants (NOBANIS 2015; EASIN 2020) and only in Europe, around 6250 alien plant taxa have been reported as spontaneous in the wild (including alien plants with a native range partially in Europe) (Arianoutsou et al. 2021). The invasiveness of each alien plant depends on various traits, as well as plant characteristics, the invasion history, the characteristics of the invaded habitat, the ecology of the alien species, the propagule pressure etc. (Milbau and Stout 2008). Measurement and monitoring of the invasiveness are essential to be

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able to guide the restoration actions; however, alien species are frequently overlooked in biomonitoring programs and are poorly represented in the multimetric indices proposed for the assessment of the biological status of ecosystems (Ruaro et al. 2021). The selection of indices and interpretation of the results may differ (Parker et al. 1999) but according to the work of Catford et al. (2012), ones of the most recommended and applicable to restoration projects, are the relative alien species richness and abundance that can be completed and improved with information about exotic species with transformation capacity of ecosystems. The type of indicator used may vary depending on the type of research or intervention being carried out, and its interpretation can be adapted to each case, making it difficult to compare with other projects. The purpose of this work is the application of a new easy-to-measure index able to quantify the effect of several Invasive Alien Plants (IAPs) on the territory and able to compare the results among regions, ecosystems and spatial scales. This Invasive Alien Plants Index (IAPI) is based on the abundances of each IAP present in the studied plots and weighted according to its area and the invasiveness degree as advised by Catford et al. (2012). A decrease in the abundance of IAPs advantages the growth of native species including the characteristic species of each habitat (Vilà et al. 2011). It is important, to consider that each species has a different impact on ecosystems, according to its invasive capacity (Milbau and Stout 2008) and can variate according to also among geographical regions. A simple way to evaluate this is to check the presence of plant species in the lists of IAS at the national or regional level and use it as a weighting element for the calculation of the index. IAS included in these catalogues have been selected by experts and it could be assumed that they have greater invasiveness than other non-natives present in that territory. Periodically, these lists are updated through the proposals of groups of experts based on advances in knowledge. These lists may have changed over time, but being an official source and a tool present in most countries, it gives it very wide applicability. For the calculation of the IAPI, all the data were retrieved from the riparian forest restoration actions carried out in the Eo River (NW Spain) for the European project LIFE Fluvial (16/NAT/ES000771), "Improvement and sustainable management of river corridors of the Iberian Atlantic Region". The main objective of this project was the improvement of the conservation status of two habitats included in the European Council Directive 92/43/EEC: The Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion*, *Alnion incanae*, *Salicion albae*) (91E0*) and the Galician-Portuguese oak woods with *Quercus robur* and *Quercus pyrenaica* (9230). Riparian forests are frequently highly fragmented and non-native plants are one of the direct causes of this state; information regarding the composition of riparian plants and their cover is essential to make a detailed diagnosis of these environments (Aguiar et al. 2011).

Materials and methods

The whole study area was divided into three different ecological units (Table 1) corresponding to fluvio-estuarine (C1), riverbank (C2), and lake (C3) environments. A total of 33 patches, covering 31.63 ha, has been restored during the LIFE Fluvial project in the Eo River in the NW of Spain (Online resource 1). All the data about the IAPs for the calculation of IAPI, were collected across one or two plots in each patch, for a total of 42 plots (see Annex I and Online resource 2 for more details). The total inventoried area is 2.53 ha that represent the 8% of restored surface (Table 1 and Annex I). Names of plant species are according to Euro + Med (2006+) and for hybrids POWO (2023); syntaxons are according to Díaz González (2020). Data about the floristic composition (relevé) was collected in all the plots during three years (2018, 2020 and 2021). In 2018, relevés were taken prior to the restoration actions. The manual and mechanical control of IAPs as part of restoration, started in 2019 and during the following years (2020–2021), data on the restored areas were collected. Ecological unit C1 have the highest number of plots (21) and inventoried area (1.41 ha), on the other hand C3 have the lowest ones (four plots and 0.14 ha). The average plot area was of 602.2 m^2,

Table 1 Characteristics of the total number of patches and plots analysed in each ecological unit

Ecological units	Patch area (ha)	Number of patches	Number of plots	Total plot area (ha) and % represented	Average of plot area (Min-Max) (m^2)
Fluvio-Estuarine (C1)	17.39	19	21	1.41 (8.09%)	670.2 (128–2025)
Riverbank (C2)	11.27	12	17	0.98 (8.68%)	575.6 (147–1980)
Lake (C3)	2.97	2	4	0.14 (4.82%)	357.8 (311–431)
Total	31.63	33	42	2.53 (8.00%)	602.2 (128–2025)

the smallest was 128 m^2 and the largest was 2025 m^2, both localised in C1. In each patch, the choice of the location of the plots was determined according to two criteria: the vegetation of selected plots areas must be representative of the patch and they must be easy to access for the operators. Plots were geolocated in the field by GPS, which allows replication of the sampling in the same area (Online resource 1). Floristic relevés have been done in each plot, using the cover abundance scale according to Braun-Blanquet (1979) system. As far as possible, floristic relevés for each plot have always been carried out at the same time of the year to compare the data in similar phenological stages of the plants. A total of 126 floristic relevés (42 per year) has been realised. The first data collection was at the same time of preparatory actions progress (2018), and the following data collections were during the monitoring of the restoration actions (2020 and 2021) taking into account that the restoration actions were carried out during 2019 and 2020. To calculate the index, the Braun-Blanquet (1979) scale was used and modified as shown in Table 2 where the "r" and the "+" of Braun-Blanquet scale were converted into the numerical values of 0.1 and 0.5 respectively (Weedon et al. 2006). The rest of the values were employed (1–5) as they are commonly reported in phytosociological relevés. For the calculation of the index (Fig. 1), all the abundance scores of the IAPs included in the official Spanish catalogue of invasive species (Real Decreto 630/2013, of August 2), were increased by multiplying the numerical value by a weighting factor (WF). The index has been tested with two WF: 2 and 1.5. For non-invasive alien plants, not included in the Spanish IAS catalogue, no WF was applied. Subsequently, all the obtained values of each alien plant, included in the inventoried area, were added to obtain the Invasive Alien Plants Abundance Index (IAPAbI) on a given date. The method has been tested in the three ecological units of the Eo basin in the context of the LIFE Fluvial project. To obtain the value of the Invasive Alien Plants Index (IAPI) of the whole study area, the IAPAbI of each one of the floristic relevés, were previously multiplied by the area in m^2 of each inventoried area and divided by the sum of all areas inventoried.

Table 2 Invasive Alien Plants cover abundance scale according to Braun-Blanquet (1979) system and modified score according to Weedon et al. (2006) for the calculation of the IAPI

Braun-Blanquet scale	% Cover	Individuals	Modified Score
r	< 0,1	Few small	0.1
+	0.1-1	Very sparsely	0.5
1	> 1 – 10	Any number	1
2	> 10 – 25	Any number	2
3	> 25 – 50	Any number	3
4	> 50 – 75	Any number	4
5	> 75	Any number	5

Results

As a first result of the work, information has been obtained from a set of floristic relevés with abundance data of the alien plants present in each plot. These data have been summarized in Annex II and have been used for the calculation of the IAPI across for years. Application of the described method in the three ecological areas C1, C2 and C3, showed a decrease of IAPAbI after the first round of control in 2020 (Fig. 2) and then, continued to descend in the C2 and C3 but not in the fluvio-estuarine zone C1. The increase of the IAPAbI during 2021 is in part due, to the detection of new pioneer IAPs (*Erigeron* spp., *Sporobolus indicus*, etc.) (Annex II), in a part of the restored areas. These plants recolonized the half-naked soil after the felling of *Eucalyptus globulus* plantations. As the IAPAbI, the IAPI was calculated with WF of 2 (Fig. 2; Table 3), returning a value of 4.19 for the year 2018 and subsequently decreased in 2020 to 2.10 and 2021 to 1.97. Calculated with a WF of 1.5 (Table 3) IAPI show a decrease in the values calculated for the entire Eo basin and in C1 and C2 but not in the C3 due to the absence, in this last zone, of IAPs included in the Spanish official list. As for the IAPAbI, IAPI decreases in the three ecological units from 2018 to 2021. The IAPI, compared to the values of IAPAbI, shows lower values in the C1, higher in the C2 and a very low difference in C3. The C1 presents the higher IAPI of 2018 with a score of 4.70 and the lower was the C3 with 3.51. The highest percentage of the variance between the IAPI of 2018 and 2021 was in C3 with 85.7%

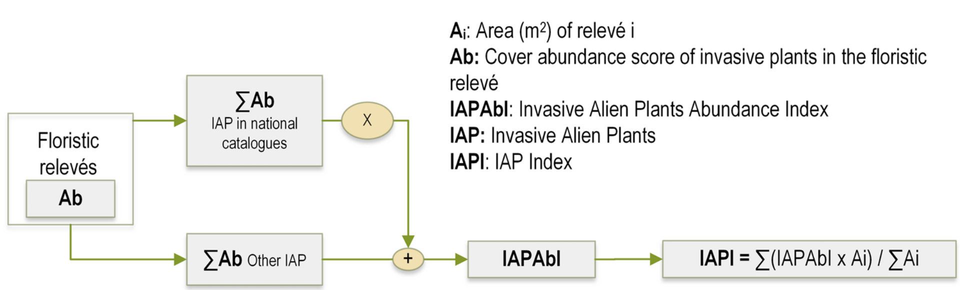

Fig. 1 Flow diagram for the Invasive Alien Plants Index (IAPI) calculation

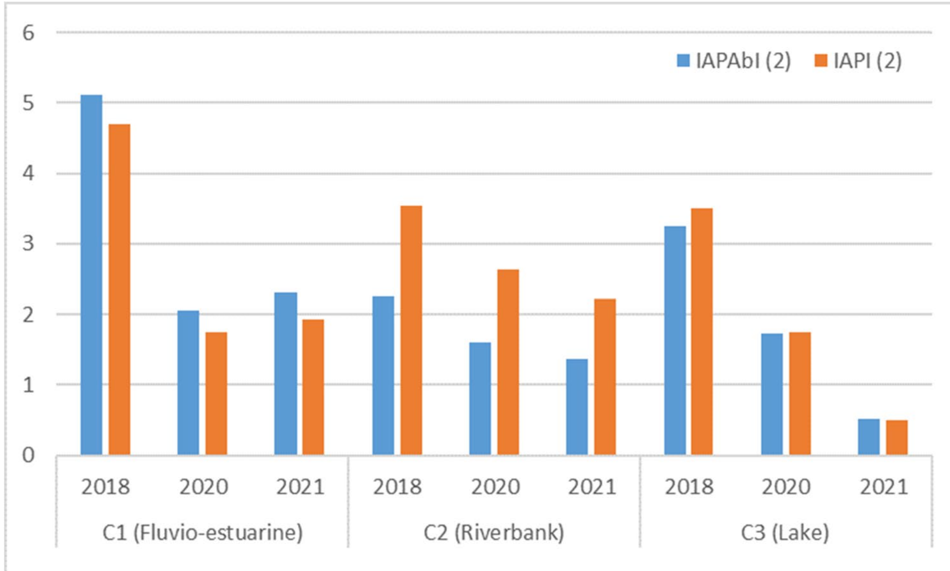

Fig. 2 Invasive Alien Plant Abundance Index (IAPAbI) and Invasive Alien Plants Index (IAPI) calculated for the three ecological units using an invasiveness weighting factor of 2

Table 3 IAPI values and improvement percentage (%impv) were obtained for the three ecological units and for the whole area applying two invasiveness weighting factors (WF)

Ecological unit	IAPI values calculated with a WF of 2				IAPI values calculated with WF of 1.5			
	2018	2020	2021	% impv 18–21	2018	2020	2021	%impv 18–21
Fluvio-Estuarine (C1)	4.70	1.76	1.93	58.9	4.44	1.66	1.81	59.2
Riverbank (C2)	3.55	2.64	2.23	37.2	3.11	2.43	2.00	35.5
Lake (C3)	3.51	1.74	0.50	85.7	3.51	1.74	0.50	85.7
Whole area	4.19	2.10	1.97	53.0	3.87	1.96	1.81	53.2

and the lowest was in C2 with a variance of 37.2%. In an overall view, IAPs decreased after the restoration actions conducted by LIFE Fluvial project in the Eo basin (Spain) parcels and is reflected in the percentage of reduction of IAPI values calculated with both WFs (Table 3). For the WF of 2 was a 53.0% and with a WF of 1.5 was 53.2% with only 0.2% of difference. The choice of using one WF or another depends on the weight to be applied to the species listed as Invasive, which in turn depends on the quality of the national catalogues of invasive species.

Discussion

Measuring the effect of IAPs is not an easy task due to the many factors involved. For environmental restoration actions, is important to know how the control actions affect the IAPs, especially for the decision-making during the actions. In this work, the abundance of all non-native species that has been collected in the inventoried area and taking advantage of the inclusion of some of these plants in the national catalogues of invasive species we have obtained and index able to detect the variations after the control actions. IAPI is not intended to be an index of biotic integrity as other authors formulate (Simon et al. 2001; DeKeyser et al. 2003; Aguiar et al. 2011), but only responds to the affectation by IAPs. It has the advantage of its simplicity, both for the collection of data, following the traditional methods of phytosociological relevés, and for its simple calculation. It also facilitates the monitoring of the IAPs control actions, giving a measure of the efforts and the progress. In this way, the IAPI relative to a specific area (a patch, a protected area, a specific and geographically defined habitat, etc.) is obtained, using discrete data from representative areas. The periodic calculation of this index allows evaluating the effect of the alien plant control during and after the restoration process. The comparison of the results before, during and after the restoration actions allows us to evaluate their dynamics.

This metric is accessible to the managers of multiple invasive plant control projects, without the need of highly qualified personnel. For its application is necessary to recognize non-native plants in the plot and the consultation of national catalogues of IAPs. A monitoring plan is also required to organize the fieldwork at the same season and at the same area and all the plots must be qualitatively and quantitatively representative of the area to be valued. The IAPI expresses, following the data observed in the field, the degree of affectation of exotic species in a natural habitat and is useful for monitoring the restoration tasks carried out in the area. IAPI decreases substantially after one year of control actions but after the second round at the C1 action, the IAPI score goes back up while C1 and C2 continue to descend. A tree layer dominated by *Eucalyptus globulus* (not included in the IAPs national catalogue) occupied the Fluvio-estuarine plots C1. After the felling of the eucalyptus trees, the land had been left with a very poor layer of vegetation, due to the allelopathic effect of the eucalyptus leaf litter during several decades. Consequently, many heliophilous pioneer herbaceous species, from the surroundings, colonize these naked areas, among them, numerous non-native species such as *Erigeron* spp., *Sporobolus indicus* or *Paspalum* spp. The abundance of these species can grow from one year to the next, especially when there is no tree cover and large naked areas are available for colonization. For this reason, the IAPI increases in the C1 but not in C2 and C3 actions where large areas were not available for recolonization by pioneer plants. However, in the long run and as long as the restoration has considered the introduction of native tree species, it is to be expected that the opportunistic groundcovers will decrease their presence due to the shading of the tree layer. The WF conditions the numerical result, but less the trend. Lower factors (1.5) had better represent the frequent cases of restored areas in which unlisted species have been eliminated and may occasionally be invaded by other opportunistic herbaceous plants capable of covering large areas in a short period of time. Higher weighting values more clearly highlight the presence of catalogued species for which there are established regulations and which must be taken into account in environmental restoration projects in protected areas. Differences between the use of one WF or another are relevant only in areas with the presence of catalogued invasive plants and could give notably different results in floristic relevés where, after the elimination of an exotic non-catalogued plant, there is a proliferation of another catalogued or vice versa. It would be interesting to do a study to evaluate how the IAPI behaves if applied among political regions, in which there are different and very variable official IAS catalogues. It is expected that in those regions where the catalogues are more extensive as numbers of taxa, the IAPI will increase more than other regions where they are smaller.

Because the final value of IAPI depends on the IAS official catalogues used, the results of the IAPI vary in each country of application, but the trend of its values over time and for the same area has the same meaning in any of them. Assuming that the different countries elaborate their lists with comparable scientific standards, these homogeneous criteria could explain the inclusion of a species as invasive or not in relation to its geographical location. However, this assumption is probably not always very true. The use of the list of invasive alien species of Union concern would make the index more comparable between countries although not necessarily more accurate for a specific geographic area.

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Code availability Not applicable.

Declarations

Ethics approval Not applicable.

Conflict of interest There are no conflicts to declare.

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