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ORIGINAL PAPER

Regional strategy for invasive alien plant species: towards an integrative and biogeographic approach to the territory of Provence-Alpes-Côte d'Azur, France

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Abstract The French national strategy for biodiversity (2011–2020) identified Invasive Alien Species (IAS) as one of the main threats. Therefore, to provide practical measures in order to prevent and to control IAS is one of the main tasks. In this context, the administration of the Provence-Alpes-Côte d'Azur region (PACA, south of France) wanted to bring consistency into the regional actions carried out on IAS. We present several steps needed to develop a regional strategy and an action plan adapted to the environmental, social, economic and political realities of this study area. Firstly, the lists of invasive and potential invasive alien plant species in the region have been established using two different scales: administrative and biogeographic. Those lists, identifying several groups of invasive and potential invasive alien species are based on three criteria for invasiveness. A regional survey of different professional sectors has also been carried out to identify all the stakeholders involved as well as their perceptions and expectations and to elaborate a regional assessment of action priorities concerning IAS. The development of the strategy took into account the status of the species, the type of environment in which they may be present (natural, semi-natural and anthropized areas) and the type of actions involved (prevention of introduction, management and control). This enables to guide and to hierarchize management actions according to the ecological, health and economic constraints.

Keywords Regional strategy · Administrative and biogeographical scales · Actions plan · Plant species lists · Management actions priorities

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Introduction

In biodiversity hotspots, biological invasions are an important cause of recent anthropogenic plant extinctions, in addition to other causes such as urbanization and agriculture (Le Roux et al. 2019). The presence and proliferation of Invasive Alien Species (IAS) can also have negative impacts on human health and the economy, with a recently estimated damage cost of 12 billion euros per year for the European Union (European Parliament 2014). In order to better evaluate species invasiveness and to prevent new IAS introductions, many alien species risk assessments were performed at local and large area scales (i.e. Branquart 2009; Celesti-Grapow et al. 2010; EPPO/EPPO

2012). That is a prerequisite for the development of a strategy and its action plan.

The qualification of the origin status of species is the first step when dealing with plant invasion in an area (Pyšek et al. 2004). Native species show a natural distribution that overlap at least a part of the study area whereas alien species show a natural distribution that is out of the area, and were intentionally or accidentally introduced (Webb 1985; Pyšek 1995; Pyšek et al. 2004). In Europe, plant species introduced before the year 1500 are traditionally classified as archaeophytes, those introduced after the year 1500 are qualified as neophytes (Pyšek et al. 2004). Neophytes can be classified into three categories following their establishment: exclusively cultivated, casual and naturalized species (Richardson et al. 2000; Pyšek et al. 2004). Several factors combined can favor the success of the invasion of a territory by a neophyte species: the correspondence between the territory of origin and of introduction (Meerts et al. 2006; Simberloff et al. 2013); the vulnerability of the ecosystem or the structure of invaded plant communities (Elton 1958; MacArthur 1972; Mooney and Cleland 2001; Prieur-Richard et al. 2002); the capacity of competitors (Blossey and Nötzold 1995; Cadotte et al. 2006; Fumanal 2007). Risk assessment that a neophyte species become invasive in a new territory incorporates these multiple factors (Weber & Gut 2004; Andreu and Vilà 2010; Brusati et al. 2014; Morais et al. 2017; Seebens et al. 2018).

The invasive characteristics of IAS vary according to environment (Mack et al. 2000) and biogeographic areas (Sax 2001). This finding is often the source, among other things, of different perceptions about the status of an alien species. Some of these species may also have positive economic, cultural or social aspects (Schlaepfer et al. 2011; Dickie et al. 2014). Assessing both positive and negative effects of invasive species on multiple ecosystem services may provide a useful framework for an effective implementation of IAS policies to different sectors of society with different values (Dickie et al. 2014). Moreover, taking into account both the negative and positive aspects of these species in the development of an IAS strategy is one of the necessary frameworks for its integration into public policies.

The Provence-Alpes-Côte d'Azur region (PACA) is located on a part of the Alpine and Mediterranean biogeographical areas defined by Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and wild fauna and flora. This region has a great diversity of climatic, ecological and geological conditions favorable to a strong biological diversity including about 3,265 native plant species (Noble et al. 2016). This floristic richness is currently threatened by multiple pressures such as the loss and destruction of natural habitats and the increase in number of IAS (Noble and Diadema 2011). Several lists of IAS have been proposed for the French continental mediterranean region (Aboucaya 1999; Brunel and Tison 2005; Mandon-Dalger 2012) and in Departments of Alpes-de-Haute-Provence and Hautes-Alpes for the Alpine area of the PACA region (Huc et al. 2011). Nevertheless, none of them led to the implementation of a strategy adapted to a territorial context which is the only guarantee to be accepted and integrated by local stakeholders.

At the request of the French State and the Région Provence-Alpes-Côte d'Azur, a regional strategy consistent with national and European guidelines and directives has been drawn up with all concerned local stakeholders. It is part of the National strategy for biodiversity 2011–2020 and the Global strategy for biodiversity in the PACA region. The objectives of this strategy were (i) to develop a scientific reference list of IAS and potential Invasive Alien Species (pIAS) at different geographical scales, (ii) to take stock of regional actions dealing with IAS and stakeholder expectations and (iii) to propose methods and an action plan shared by all the stakeholders involved in the management and control of IAS and pIAS.

Method

Elaboration of IAS and pIAS lists

To take into account the specific floristic characteristics related to the two distinct biogeographical part of the PACA region, the species were analyzed at the geographical scale of (1) the whole PACA region, (2) the Mediterranean biogeographical area and (3) the Alpine biogeographic area.

A list of confirmed neophyte species (i.e. with last observation equal to or after 1990) was established at a regional scale according to the occurrence data gathered in the SILENE database (https://silene.eu/). The SILENE database is a French regional platform

of the national SINP (Système d'Information de l'Inventaire du Patrimoine naturel) program carried by the Ministry of Ecology and aiming to promote synergy between the actors for the production, management and valorization of data on biodiversity. The National Mediterranean Botanical Conservatory (CBNMed) and the National Alpine Botanical Conservatory (CBNA) are responsible for centralizing and validating these data relating to the flora on their respective territories (from a network of professional and amateur botanists – citizen science excluded). The national botanical conservatories produce reference lists of vascular flora present in their territories, called catalogs. According to the catalog of the vascular flora of the PACA region (Noble et al. 2016), neophyte species have been classified into different categories according to their establishment in the study area (Noble et al. 2016).

This makes it possible to distinguish exclusively cultivated species, casual species and naturalized species. Only naturalized species are taken into account for invasiveness evaluation (Pyšek et al. 2004) (Fig. 1). In addition, IAS absent from the PACA region but present in areas bordering the south-east of France were also considered (Muller 2004; Brunel and Tison 2005; Paradis et al. 2008, Celesti-Grapow 2009; Weber 2003; unpublished data in appendix 2). Taxonomy and nomenclature of species follow the French national index TAXREF v11 standard (Gargominy et al. 2017).

To classify naturalized species into different categories and evaluate species invasiveness, several criteria were defined according to (i) mean plant cover

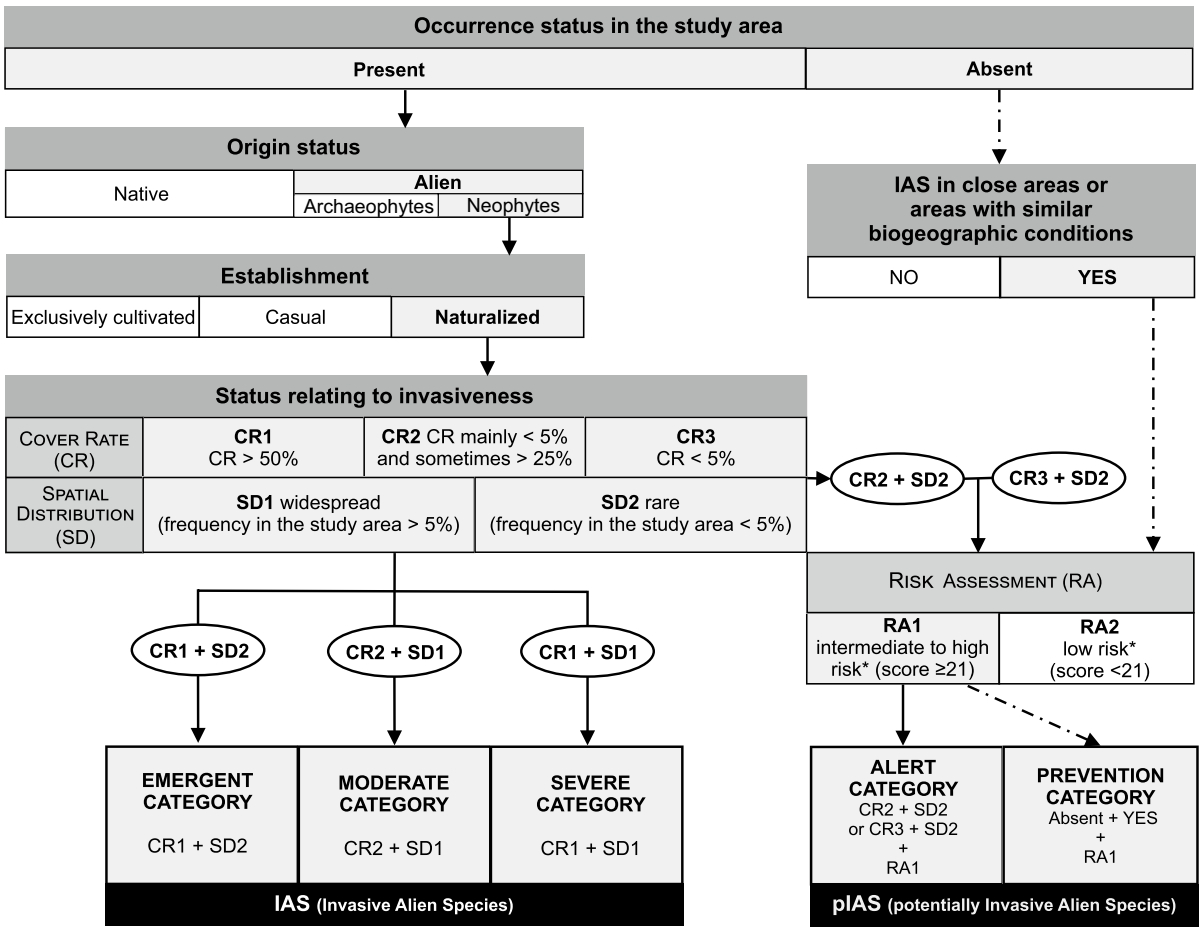


Fig. 1 Criteria for defining and listing IAS and pIAS at the study area scale (full line arrow designed present species in the study area; dotted arrow designed absent species in the study area). * risk assessment following Weber and Gut 2004)

at the population scale for each study area (PACA region; Mediterranean and Alpine biogeographical regions), (ii) species spatial distribution at the regional and at the biogeographical scales and (iii) risk assessment only for the species naturalized or absent in the study area but listed as IAS in areas bordering the south-east of France (Fig. 1).

Mean plant cover

First, the plant cover corresponds to the vertical projection on the ground of its aerial organs (Allorge 1922). Plant cover was evaluated at the scale of the species presence area and not at the scale of its potential habitat on the site and only where natural regeneration was observed. The data came from surveys of the SILENE database (https://silene.eu/, consulted on 02/12/2017) for which an abundance-dominance coefficient (Braun-Blanquet et al. 1952) was assigned to each inventoried species. The national botanical conservatories and their network carry out some inventories, observations and collect information in the field, which generate important raw data, validated, recorded, analyzed and shared. The mean plant cover was obtained taking into account the most representative abundance-dominance class of coefficients recorded in all the presence area of the inventoried species and adjusted to expert opinion when there was a lack of data. The frequency of observation was also taken into account in the evaluation of this criterion to avoid generalizing a very localized behavior of a species on a larger geographical scale. Four categories of mean cover rate abundance-dominance coefficients were attributed:

0 species absent from the territory (no observation),
CR1 mean plant cover in its presence areas of less than 5% (abundance-dominance coefficient corresponding to: i, r, + or 1),
CR2 mean plant cover in its presence areas regularly below 5% (abundance-dominance coefficient corresponding to: i, r, + or 1) and sometimes greater than 25% (abundance-dominance coefficient corresponding to: 3, 4 or 5),
CR3 mean plant cover in its presence areas regularly above 50% (abundance-dominance coefficient corresponding to: 3, 4 or 5).

The coefficients categories assigned to each species were submitted to the botanists' opinions using the Delphi technique (Hsu and Sandford 2007).

Species spatial distribution at the regional or the biogeographical scale

In order to measure the species frequency, the PACA region was divided into 1449 cells of a 5 × 5 km grid. For each (neophyte) naturalized species, the spatial distribution was simply deduced by calculating the number of cells of presence brought to the total number of cells. Only the precise and post-1990 data of the SILENE database (Delauge et al. 2013; https://silene.eu/) were selected and used. To categorize the spatial distributions of species on each (regional and biogeographical) study area, we used a threshold of 5% of cells (i.e. 72 cells) which allows us to distinguish:

- Species absent from the study area (no recent observation),
- *SD1* species whose percentage of presence in the study area concerned is less than 5%: an uncommon species in this territory,
- *SD2* species whose percentage of presence in the study area concerned is greater than 5%: a species that is fairly frequent to frequent in this territory.

Risk assessment

Thirdly, a risk analysis was performed on some alien plant species. It was applied to (i) IAS known in close areas or areas with similar biogeographic conditions but absent from the PACA region (Appendix 2) and to (ii) recently naturalized species which didn't form monospecific stands (Fig. 1). The Global Compendium of Weeds (http://www.hear.org/gcw/), the Delivering Alien Invasive Species Inventories for Europe (http://www.europe-aliens.org/) and the Global invasive species database (http://www.iucngisd.org/gisd/) were consulted to identify IAS from other near-climate regions of the world: Mediterranean and Alpine biogeographical regions outside of France were determined using Köppen-Geiger mapping (Kottek et al. 2006). The risk of proliferation in the PACA region could be defined for each of these species according to the Weber and Gut (2004)

analysis. This analysis is a scoring system, composed of biogeographical and ecological questions to assess the invasion potential of neophyte species. This risk is divided into three categories: low, intermediate and high. "High risk" (28–39 points) concerned species that are likely to become a threat to natural communities if naturalized, "intermediate risk" (21–27 points) concerned species that require further observation and "low risk" (3–20 points) concerned species that are unlikely to pose a threat to natural communities. For this study, we considererd two levels: intermediate to high risk (RA1) and low risk (RA2).

Combining these three criteria concerning the status relating to invasiveness (mean plant cover at the population scale, spatial distribution at the regional or biogeographical scale, risk assessment), several categories of IAS and pIAS were defined. For IAS: “severe”, “moderate” and “emergent” categories. For pIAS: “alert” and “prevention” categories (Fig. 1).

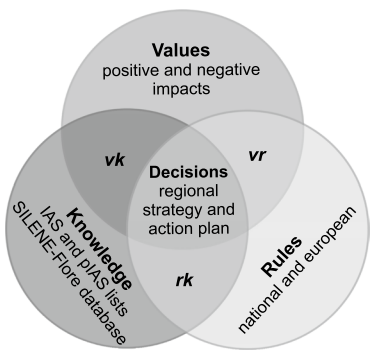
Species diagnostics

For each species identified as IAS or pIAS for the Provence-Alpes-Côte d’Azur region thanks to the methodology previously described, the geographical origin and habitat were specified on the basis of litterature and floristic surveys and databases (data of the SILENE database, Global invasive species database, Delivering Alien Invasive Species Inventories for Europe, Global Compendium of Weeds). In order to give keys to help decision-making, the IAS or pIAS were then classified—foreach category (“severe”, “moderate”, “emergent”, “alert” or “prevention”)—according to their presence either in natural or semi-natural habitats or only in highly anthropized habitats in the PACA region. The following types of habitats were considered natural or semi-natural: inland surface waters; shores and riparian woodlands; mires, bogs and fens; seasonally wet and wet meadows; dry grasslands; woodlands, forests, maquis, mattoral, brushes and scrubs; coastal dunes and sandy shores; coastal cliffs and inland cliffs. On the contrary, agricultural environments (i.e. regularly or recently cultivated agricultural, horticultural and domestic habitats) and human environments (i.e. constructed, industrial and other artificial habitats) were considered highly perturbed habitats.

In order to assess how the PACA region and the five departments (Hautes-Alpes, Alpes-de-Haute-Provence, Bouches-du-Rhône, Var, Vaucluse, Alpes-Maritimes) within the PACA region are subject to IAS in relation to other areas of the planet, the invasive alien species diversity (S_{Inv}) per unit area (A, in km^2) was calculated (S_{Inv}/A) (X 10^5) i.e. the IAS diversity per km^2 (per 100 000 km^2) and compared (Turbelin et al. 2017).

Concerted development of the regional strategy and the action plan

In order to develop a regional strategy to limit the introduction and spread of IAS and pIAS and help territorial stakeholders to manage these species which is coherent with the multiple challenges of the study area, an action plan has been co-constructed by the two national botanical conservatories during two years with the various actors of the territory, according to the decision context following the value-rules-knowledge model (vrk model, Gorddard et al. 2016) (Fig. 2). This model helps diagnose constraints in decision processes, and the development of responses adapted to complex problems. A survey was therefore conducted with territorial stakeholders during one year in this study. Questions asked in this survey



vr: Territorial workshops (Western coast/Eastern coast/hinterland and mountain) raised concerns about the positive aspects of IAS, especially for forestry and horticulture, and the inclusion of biogeographical areas. Rules-based on national and European rules.

vk: Regional survey of the different actors. Spatial planning included the various types of habitats (natural with or without protection, semi-natural and urban).

rk: Technical Committee consultation on knowledge base of adaptation options enabled deliberation about the rules and values that underpinned the options.

Fig. 2 Regional strategy development scheme according to the perspective on decision making from the decision-context perspective vrk: values, rules and knowledges (from Gorddard et al. 2016)

focused on: (i) the type of organization involved, (ii) the perception of IAS by the stakeholders, (iii) the assessment of their knowledge of IAS, (iv) the identification of issues, expectations and challenges of developing a regional strategy and (v) the type and precise description of the actions carried out on IAS (Terrin et al. 2013). Territorial workshops at the four main sectors scale (west coast, east coast, middle-country and mountains) identified thanks to the survey were organized. A technical committee gathering some botanical experts of the study area was consulted in order to support the various choices of options at the time of the construction of the regional strategy and its action plan.

Results

Neophyte species classification

A typology of the categories and their definitions are described in Table 1. The IAS status takes into account all naturalized species that have the potential to spread over a considerable area (Table 1; Richardson et al. 2000; Pyšek et al. 2004).

Other recently naturalized species with an intermediated or high score for the risk assessment, and IAS known in close areas or areas with similar biogeographic conditions which are not yet present, are defined as potential Invasive Alien Species (pIAS; Table 1).

Overview of neophyte species in the vascular flora of the PACA region

4109 plant (vascular flora) species are present in the PACA region (confirmed presence and observation data ≥ 1990). Of these species, 3265 (79%) are native, 101 (2%) are archaeophytes and 743 are neophytes. Thus, 18% of the plant species currently present in the PACA region are introduced (archaeophyte or neophyte species). Of these, 121 are IAS i.e. 3% of the vascular flora present in the PACA region. Categorization highlights 150 plant species as pIAS.

These IAS were divided into 29 species of the severe category (24%), 46 of the moderate category (38%) and 46 of the emergent category (38%). The

Table 1 Categories of IAS and pIAS used to prioritize management in natural and semi-natural habitats

Categories	Definitions	Status
Severe	**(CR1)** show often high mean plant cover (> 50%) at a population scale AND **(SD1)** Widespread (spatial distribution in the study area > 5%)	Invasive Alien Species (IAS)
Moderate	**(CR2)** show occasionally high mean plant cover (mainly < 5% and exceptionnaly > 50%) at a population scale AND **(SD1)** Widespread (spatial distribution in the study area > 5%)	
Emergent	**(CR1)** show often high mean plant cover (> 50%) at a population scale AND **(SD2)** Rare (spatial distribution in the study area < 5%)	
Alert	**(CR2)** show occasionally high mean plant cover (mainly < 5% and exceptionnaly > 50%) or **(CR3)** always low mean plant cover (always < 5%) at a population scale AND **(SD2)** Rare (spatial distribution in the study area < 5%) AND **(RA1)** Weber and Gut (2004) high or intermediate risk (score ≥ 21)	potential Invasive Alien Species (pIAS)
Prevention	Absent in the study area AND Listed as IAS in some close areas or areas with similar biogeographic conditions AND **(RA1)** Weber and Gut (2004) high or intermediate risk (score ≥ 21)	

Spatial distribution (SD) was calculated on 5 × 5 km grid cells at the study area scale; mean plant cover (CR) was estimated with abundance-dominance coefficient at a population scale. Risk assessment (RA) was defined according to the Weber and Gut (2004) analysis

list of pIAS includes 150 species, of which 127 (84.7%) are in the alert category and are rather rare, or localized in certain sectors in the PACA region, and 23 species are in the prevention category and are absent from the PACA region (Appendix 1).

More than half of the IAS introduced in the PACA region come from the Americas (57% of species) and mainly from North America (39% of the species). Asia is the second continent of origin of these species. Europe and Africa, mainly South Africa, are also areas of origin for these species and only a small proportion currently comes from Australia (e.g. *Hakea sericea*, *Acacia dealbata*) or other parts of the Mediterranean basin (e.g. *Pyracantha coccinea*, *Medicago arborea*) (Fig. 3).

Nevertheless, the origin area of IAS categorized in the emergent category is mainly Central and South America and Asia whereas for pIAS, their origin area is mainly North America and Asia as well as areas with a Mediterranean climate (Australia, South Africa, Chile in particular) (Fig. 3).

The the habitats that are the most affected by IAS in the PACA region are heavily anthropized habitats (including peri-urban areas, urban areas, private gardens, roads, wastelands, agricultural land margins, etc.) with 89 IAS known to spread in human environnements. 43 IAScolonize agricultural environments and 65 IAS adapt in aquatic habitats (riverbanks, riparian forests, streams, swamps, etc.) in particular in shores and riparian woodlands. Rocky (26 IAS) or dune (23 IAS) habitats are also sensitive to these species because they are subject to recurrent disturbances, particularly those located along the coastline (Fig. 4).

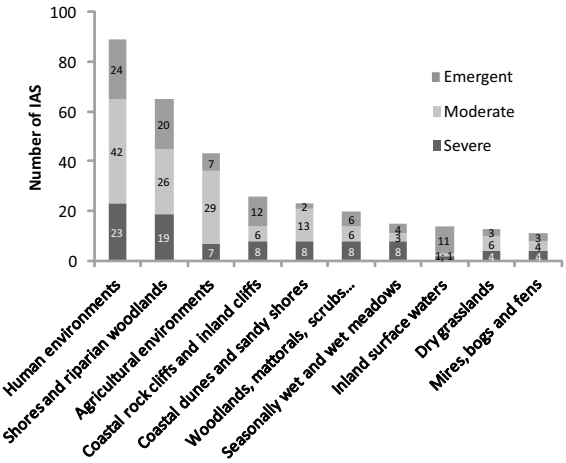


Fig. 4 Distribution of the 121 IAS for each category (emergent, moderate, severe) and for each colonized habitats

Geographical and biogeographical distribution of species

Within the PACA region, the departments of Alpes-Maritimes and Vaucluse are the most impacted by IAS (Table 2) and the ratio between the IAS diversity and the area colonized (S_{Inv}/A) (X 10^5) exceeds 2200.

In the PACA region, areas where the diversity of IAS is important are mainly (1) the Mediterranean coastline which is a highly urbanized sector, (2) the south-west of the Vaucluse department where industrial and agricultural areas are present and (3) the medium and low valleys of the Durance, which are substantially altered or regularly disturbed environments (e.g. artificialization of rivers, floods) (Fig. 5). Netherless, in some parts of the region, few or no IAS have been identified.

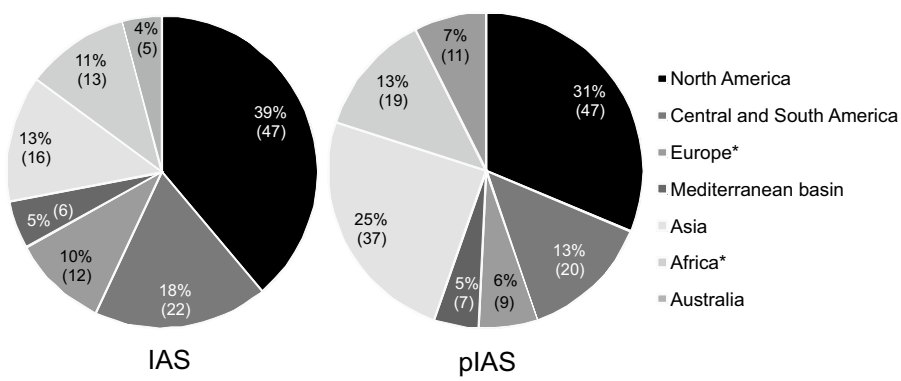


Fig. 3 Proportion and number of the 121 IAS and 150 pIAS of the PACA region following their geographical origin. *Mediterranean basin excluded

Table 2 Distribution of IAS (S_{Inv}: number of IAS inventoried), area of territories (A) in km^2 of the PACA region (areas source: INSEE 2012)

	France*	PACA Region	Alpes-de-Haute-Provence	Hautes-Alpes	Alpes-Maritimes	Bouches-du-Rhône	Var	Vaucluse
Area (A)	547,561	31 822	6 925	5 546	4 299	5 087	5 973	3 567
S_{Inv}	152	121	71	50	97	99	101	89
(S_{Inv}/A)(X 10^5)	27,76	380	1025	902	2256	1946	1691	2495

The equivalent number of IAS (species diversity) per 100 000 km^2 was calculated (S_{Inv}/A) (X 10^5). * data from Turbelin et al. 2017

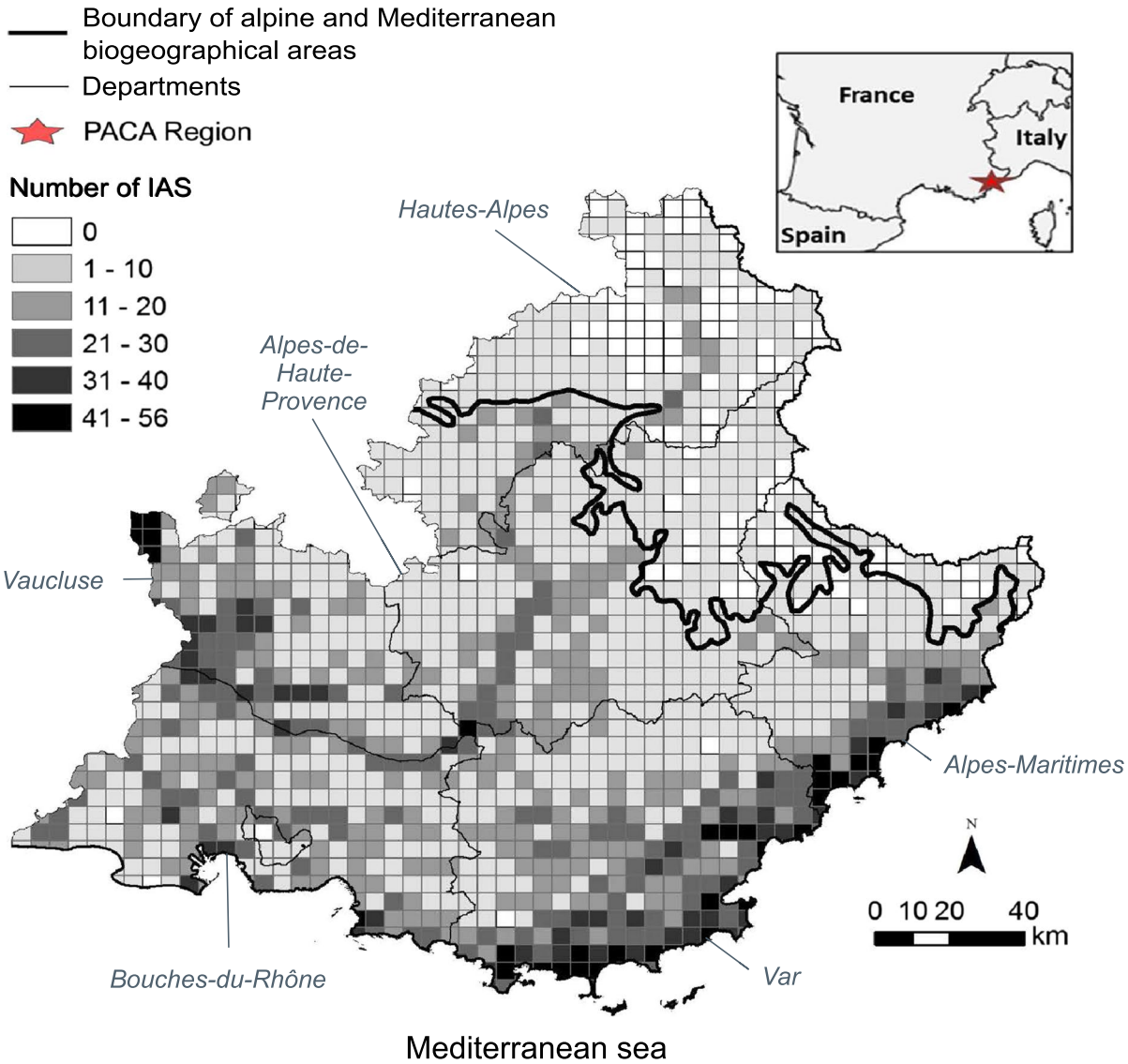


Fig. 5 Species richness per 5×5 km grid cells of the 121 IAS observed in the PACA region (SILENE database records, https://nature.silene.eu/)

Only a few severe IAS are common in the PACA region and distributed over almost the entire territory. These include *Ailanthus altissima*, *Robinia pseudoacacia* and *Artemisia verlotiorum*. Other IAS are indeed present along the Durance (e.g. *Bidens frondosa*, *Buddleja davidii*, *Ailanthus altissima*, *Symphyotricum* x *salignum*, *Xanthium orientale* subsp. *italicum*).

Several severe IAS have already colonized a large part of their potential habitats. However, they are currentlypresent, in natural or semi-natural environments, only in parts of the PACA region (*Baccharis halimifolia*, *Carpobrotus* spp., *Cortaderia selloana*, *Ludwigia peploides*, *Acacia dealbata*, etc.). 46 IAS have been categorized as emergent species. Some of them have recently been discovered in the Vaucluse department, for example, *Alternanthera philoxeroides* in 2014.

115 IAS observed in the PACA region are also present in the Mediterranean area, of which 80 are considered invasive only in this area. 41 IAS are present in the Alpine area, of which only 6 are only invasive in this area (*Erythranthe guttata*, *Sporobolus vaginiflorus*, *Berteroa incana*, *Lapsana communis* subsp. *intermedia*, *Bunias orientalis*, *Matricaria discoidea*). The three last species have been also classified in the Mediterranean area as pIAS (in the alert category). 35 neophytes, i.e.nearly 29% of species are IAS in both the Alpine and the Mediterranean areas.

Many of IAS who have recently been introduced in the region have managed to naturalize and spread out of their introduction sites, e.g. *Elide asparagoides*, *Hakea sericea*, *Hakea salicifolia*, *Alternanthera philoxeroides*, *Hetranthera* sp., *Senecio angulatus,* etc. Finally, 28 neophyte species are categorized in the prevention category, which means that early detection is essential for quick reaction if they are discovered in the PACA region—because they are currently absent from the study area and could become invasive if they were introduced(Appendix 1).

Expectations and priorities of regional actors

The survey enabled to collect the opinions of 104 different organizations representing some managers of natural areas (aquatic environments, protected natural areas, etc.), but also nature conservation associations, environmental research departments, scientific research organizations, agricultural professionals, government departments, plant prescribers and urban and regional planners, development companies, and plant producers.

The expectations and priorities of regional actors (industry and trade, transporters, retailers, resource managers, decision-makers, scientists and other stakeholders) were identified and analyzed in order to define a regional strategy that is accepted and operational by all stakeholders. Their main expectations were to (i) take into account the different types of habitats colonized by IAS in the management recommendations, (ii) define management priorities in natural and semi-natural environments to help local key stakeholders establish their own action plan at a local scale and finance their projects, (iii) take into account the economic stakes of some of these species, (iv) work in consultation with socioprofessionals that use these IAS to develop tools to limit their introduction and spread, (v) pool information, (vi) coordinate and operate a network to facilitate the alert to the competent organizations in case of early detection, (vii) provide technical and financial support (Terrin et al. 2013).

The regional strategy and its action plan

In order to take into account the expectations of the various organizations and the survey results made, a decision support table based on the neophyte species categorization (“severe”, “moderate”, “emergent”, “alert” or “prevention”) and combined with different types of habitats in the IAS presence area (Table 3). This combination of criteria made it possible to develop actions around three axis: (i) management (prioritization, coordination), (ii) prevention (limitation of introduction and spread, awareness raising, training, communication), (iii) knowledge improvement (ecological features, distribution, etc.).

This decision support table helps managers of natural areas define their priorities by referring to management priorities. Potential impacts of IAS on human health and security were considered as priority 1 for all categories of IAS as impacts on natural and semi-naturals environments (Table 3). Consultation with the horticultural and landscape socioprofessionals can also be undertaken to create a list of plant species consensus and to define some restriction of uses depending on the habitat where the neophyte species is introduced (e.g. in urban and peri-urban

Table 3 Decision support table for the management and use of IAS and pIAS in the PACA region according to the type of habitats or areas

Spatial Approach	Species Categories				
	IAS			pIAS	
	Emergent	Severe	Moderate	Alert	Prevention
Priority areas 1: Protected areas	**1** + Ban the use	**4** or **1 if issues*** + Ban the use	**5** or **1 if issues*** + Ban the use	Non intervention or **1 if invasive population** + Discourage and if possible ban the use	**1** if the species is detected on the territory
Priority areas 2: Natural or semi-natural environment except protected areas	**2** or **1 if issues*** + Ban the use	Not prioritary or **1 if issues*** + Ban the use (except for forestry operations)	Not prioritary or **1 if issues*** + Ban the use (except for forestry operations)	Non intervention or **2 if invasive population** + Discourage and if possible ban the use	**2** if the species is detected on the territory
Priority areas 3: Semi-natural environment strongly influenced by humans and agricultural environment	**3** or **1 if issues*** + Ban the use	Not prioritary or **1 if issues*** + Ban the use (except for forestry operations)	Not prioritary or **1 if issues*** + Ban the use (excluding forestry operations)	Non intervention + Discourage and if possible ban the use	**3** if the species is detected on the territory
	IAS and pIAS lists for producers, sellers and plant prescribers (in anthropized areas)				
Priority areas 4: Anthropized areas (urban/peri-urban environment and private gardens)	**Consensus List** Species to be withdrawn from trade and plantations		**List of restrictions of usage according to environment** Species to avoid planting near natural environment where they could become invasive (especially for private gardens and urban environment)		

From 1 to 5: Priority of management actions in the PACA region (1 being the highest priority and 5 the lowest priority). * Issues: presence areas where IAS populations compete with a population of species with conservation concerns, i.e. rare or threatened native species (biodiversity issues) and presence areas where IAS populations causesecurity or human health issues

habitats and in gardens). Recommendations for planting can also be defined according to the status of species and habitats colonized in order to take into account the economic stakes of some of them.

The resulting action plan is based on the main orientations of the regional strategy and includes operational actions defined in consultation with regional stakeholders who participated in the regional survey, territorial workshops or the technical committee.

Thus, 17 objectives were developed within five main axis which are (i) the improvement and information sharing on IAS and pIAS, (ii) introduction limitation of IAS and pIAS in natural or semi-natural environments and species management by prioritization of actions, (iii) introduction limitation and some IAS and pIAS management in anthropized areas, (iv) communication, awareness raising and stakeholders training and (v) governance and animation. In all, 59 actions were proposed in this action plan to meet these objectives. This action plan has been made operational thanks to the implementation of actions since 2014 by project managers from the national botanical conservatories. The list of IAS and pIAS in the PACA region was updated in 2020 (Cottaz et al. 2020). All species are described on an internet platform called INVMED-Flore (http://www.invmed.fr).

Discussion

Strategy development

The PACA region is particularly rich in native species (3265 species) but also in alien (archaeophytes and neophytes) species (844) (Noble et al. 2016). Among these neophytes species, 121 are IAS amounting to 3% of the vascular flora present in the PACA region observed in a natural and semi-natural environment (Fig. 3). Thus nearly 14% of naturalized species have become invasive, which is more than the 10% rule of Williamson and Fitter (1996). As in other Mediterranean climate areas such as California (DiTomaso and Healy 2007; Baldwin et al. 2012), the Mediterranean area of the PACA region is subject to a strong disruption by IAS, particularly in mainland areas. The number of IAS per 100,000 km^2 in the PACA region is equivalent to that of islands such as Guadeloupe ($S_{Inv}=38$; (S_{Inv}/A) (X 10^5)=2,334) and is much greater than that of the Netherlands which is the most invaded mainland territory with a land area above 3000 km^2 ($S_{Inv}=92$; (S_{Inv}/A) (X 10^5)=273) (Turbelin et al. 2017). This outcome is supported by the fact that 80% of IAS listed in mainland France are present in this region, in particular in its Mediterranean area (Muller 2004).

Our ability to predict the identity of future IAS is largely based on knowledge of their invasion history in other countries (Brusati et al. 2014; Seebens et al. 2018). In this way, the development of several lists of neophyte species, including lists of IAS but also list of pIAS, considers not only the status of species but also type of habitat, protected areas and biogeographical areas. Taking all these criteria into account makes it possible to define action priorities which are adapted on area, habitats and target stakeholders (Fig. 2, Table 3).

In regard to the different habitat types, disturbed environments whether highly anthropized or agricultural, have the highest species diversity of IAS in the PACA region, regardless of the biogeographic area considered. They are resource-rich environments with relatively low interspecific competition and environments where interspecific relationships are disrupted and unstable, which favors the development of IAS (MacArthur 1970, 1972; Levine and D'Antonio 1999; Mack et al. 2000). Aquatic habitats are exposed to the introduction of neophyte species (e.g. revegetation of banks, aquariophily), connected to each other and often remodeled by humans, which favors the introduction and proliferation of IAS. In addition, they are known to be sensitive to IAS (Stohlgren et al. 1998; Stohlgren and Schnase 2006). Rocky or dune habitats are fairly well represented by the highly urbanized Mediterranean coastline (Médail and Diadema 2006). On this coastline, there are several often planted IAS, which are escaped from gardens and established in natural environments on the coastline (*Opuntia* spp., *Agave americana*, *Carpobrotus* spp., *Senecio angulatus*, *Freesia alba*, etc.). Two main causes can explain these results. The first concerns the climate: warmer winter temperatures can favor a more diversified and more important establishment of neophyte species. The two climatic influences of the PACA region clearly show this phenomenon since only 29% of the IAS in the region are in both the Alpine and the Mediterranean areas. The second concerns urbanization. Indeed, the urbanization rate is higher in the four Mediterranean departments (Var, Vaucluse,

Bouches-du-Rhône and Alpes-Maritimes) than in the two Alpine departments (Alpes de Haute-Provence, Hautes-Alpes) (Vimal et al. 2012).

In the second part, to have a global and effective action against IAS, it was necessary to take into account the expectations of different stakeholders in order to reach a consensus. The regional strategy and action plan prioritizes or directs actions towards some of these species in four different priority areas (Table 3) and takes into account other positive or negative impacts such as human health, security and the economy in accordance with the local context. With regard to regional issues, the perceptions of these species are very different according to regional stakeholders, habitats colonized and areas concerned. Indeed, depending on the area and the habitat where the IAS is present, the invasiveness of the species is not always expressed, and the potential negative effects may vary (Vilà et al. 2006). In addition, many IAS are ornamentals, marketed and used in urban and suburban environments or related to productions such as forestry. The positive social, cultural, landscape and economic aspects of some of these species therefore have an influence on the perception of these species, particularly by the general public, in the same way as the negative aspects of these species have an influence on biodiversity, health and the economy (Andreu et al. 2009; Claeys 2010). In this case, a consensus list of usage restrictions according to the area where is introduced an IAS or pIAS allows the use of some of them (e.g. private gardens and urban areas vs suburban areas, natural areas or semi-natural areas).

The decision support table for the management and use of IAS and pIAS (Table 3) resulted from a concerted approach with all stakeholders in various business sectors (horticultural, landscaping, forestry, etc.). Thus, the regional strategy for IAS in PACA was concretized through the development of an action plan. This crucial step fueled a broader, responsive and evolving governance process (Colloff et al. 2017). Also, the regional approach was established with the objective of being compatible with the other underway strategies at regional, national and European scales (Genovesi and Shine 2003) in order to improve prevention and management actions and facilitate governance. Indeed, a high proportion of IAS originates from the Mediterranean climate areas, particularly from the American continent (California). A few species originating from mountainous areas are present in areas with a similar climate in the PACA region, as for example the giant hogweed (*Heracleum mantegazzianum*) or *Lapsana communis* subsp. *intermedia* which both are native to Eastern Europe (Caucasus, Iran, Pakistan, etc.). Besides, an emerging proportion of species originating from Asian and other Mediterranean climate regions (Australia, South Africa) of the world were established for the PACA region. This momentum reflects the expansion of commercial networks and environmental changes (Seebens et al. 2018) which makes it necessary to collaborate with other countries.

Implementation of the regional strategy

The implementation of the regional strategy for alien plant species has been underway for seven years, and is materialized through a framework document: an action plan. It doesn't only focus its actions on the IAS control but also integrates prevention, awareness raising, communication, training of professionals as well as the general public, differential IAS management priorities according to areas where the population is introduced, restoration of disturbed environments, actions to improve knowledge on these species and to share information. Only the involvement of all the professionals concerned by these IAS in the study areas and their actions on these species in a concerted and consensual way will allow the impact engendered by these species to be reduced (whether economic, social or environmental). Nowadays, the regional strategy has been used by stakeholders in different protected areas and integrated in some local development planning, landscape planning or urban development planning. But this requires constant improvement, whether to update the IAS and pIAS lists or the database settings, to coordinate a network or to develop tools addressed to different stakeholders.

To remain applicable, a regular update of species lists is necessary to improve prevention and early detection actions. The suggested methodology for classifying neophyte species is based on current knowledge. These lists of IAS and pIAS in the PACA region for each of the Mediterranean and the Alpine biogeographical areas have to be regularly updated with knowledge improvement on their spatial distribution, their biology, ecology and levels of establishment and invasion features of these species in the PACA region especially in order to be able to

carry out prevention actions (Seebens et al. 2018). At the same time, an improvement of the occurrence database parameters must be carried out. For example, for some human-favored species such as Austrian black pine (*Pinus nigra* subsp. *nigra*), Spanish plane tree (*Platanus x hispanica*) or Atlas cedar (*Cedrus atlantica*), presence data currently includes both sites where these species are planted and do not regenerate naturally, and sites where these species are planted and regenerate naturally. Therefore this criterion was often assessed using expert opinion to take into account only the sites with natural regeneration. Henceforth, establishment status is requested for all new stations of neophyte species.

For the strategy to be effective, networking of stakeholders who carried out some prevention or control actions has been developed. Communication with the general public and the professionals should therefore take this networking into account, as well as the opinions expressed by the stakeholders concerned by these species and adapt its communication tools and messages according to the type of public and the objectives set. The ecological issues related to the conservation of native species and natural habitats vary betwen the different IAS and pIAS, the type of invaded habitat and the study area. Indeed, this postulate assumes that: (i) the conservation issue is higher in natural and semi-natural habitats than in anthropized or urbanized habitats and (ii) the ability of an IAS to form dense populations increases its potential to further impact native plant communities through plant competition. Human security issues have also been addressed with a similar priority to conservation issues, as impacts on human health and welfare are often considered in policy decision-making more important than impacts on biodiversity. The economic impacts were also taken into account through co-elaboration of neophytesconsensus lists with different stakeholders with economic stakes (e.g. in urban environments, or for forestry operations in natural and semi-natural environnements). Therefore, improving the communication between all stakeholders, which requires the guidance of a network facilitator, is necessary to allow actions on IAS in some areas and coordinate actions. Accompanying different stakeholders involves developing new tools. The regional baseline assessment enabled to identify the issues relating to IAS as well as the expectations and priorities of regional stakeholders concerning the regional strategy and its action plan, such as feedbacks on eradication operations, tools to track the effectiveness of their control operations, or management summary for some IAS and pIAS concerned with long-term management to ensure biodiversity preservation.

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