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Risk analysis of potential invasive plants in Spain

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Summary

Once non-native species become established in a new region, they are extremely difficult to eradicate or control, suggesting an urgent need for the development of early warning systems to determine the probability of a given species becoming invasive. Risk assessment schemes are valuable tools to diminish the risk of invasion and to concentrate resources on preventing the entrance and spread of those species with higher risk of invasion. For many European countries, plant species not yet introduced to the country and with high invasive potential have not been identified. The present study aims to identify and rank non-native plant species that could potentially become invasive in Spain if introduced. As a first step, a plant data set was pre-selected for screening, containing invasive plants in neighbouring countries and in other Mediterranean regions of the world but not present in Spain. A preliminary list of 80 species was obtained, Leguminosae being the most represented family (15%) and gardening (62%) the most common pathway of introduction. As for the potential European Nature Information System (EUNIS) habitats to invade, heath land and scrubland habitats types (F; 19%), followed by constructed, industrial and artificial habitats (J; 14%) and woodland and forest habitats (G; 13%) seem to be the habitats most at risk despite F and G habitats currently being the least invaded in Spain. We ranked these potential invasive species using the Australian Weed Risk Assessment system and a Risk Assessment for Central Europe developed by Weber & Gut (2004) [Weber, E., & Gut, D. (2004). Assessing the risk of potentially invasive plant species in central Europe. *Journal for Nature Conservation*, 12, 171–179]. Most species received intermediate values in both tests. The species with higher scores were mainly aquatic plants and should be prohibited or kept out of trade. *Chromolaena odorata* (Asteraceae) obtained the highest score in both tests and therefore is the species with the highest risk to become invasive in Spain if introduced.
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Introduction

Invasion by non-native species represents one of the greatest threats to biodiversity worldwide and is considered a major component of global change (Mack et al. 2000; Mooney & Hobbs 2000). In addition to affecting ecosystems and contributing to the local extinction of native species, invasive non-native species can also cause major socio-economic damage (Pimentel et al. 2005). The introduction of non-native species has increased dramatically in frequency and extent in recent decades, as human movements have become more global and international trade has increased (McNeely et al. 2001). This trend has entailed an increase in the likelihood of new invasion events with subsequent negative ecological and socio-economic impacts (Levine et al. 2003; Mack et al. 2000; Pimentel et al. 2005; Vitousek et al. 1997).

Once introduced plant species are established in a new region, they are extremely difficult to eradicate or control (Duncan et al. 2003; Rejmánek et al. 2005). Thus, preventing new non-native invasions is, by far, the most environmentally desirable and cost-effective management method (Wittenberg & Cock 2001). Consequently, there is an urgent need for the development of early warning systems to determine the probability of a given species becoming invasive (Groves et al. 2001; Panetta & Scanlan 1995).

For plants, research on (1) the historical events related to introduction (Pyšek & Jarosík 2005; Pyšek & Richardson 2007; Rejmánek et al. 2005), (2) the key species traits associated with invasive species (Goodwin et al. 1999; Reichard & Hamilton 1997; Rejmanek & Richardson 1996) and (3) the characteristics of invaded habitats (Burke & Grime 1996; Lonsdale 1999) have provided the basic information to predict the invasion success in the new region (Pyšek & Richardson 2007; Richardson & Pyšek 2006; Williamson 1999), and therefore for risk assessment analysis (Daehler & Carino 2000; Keller et al. 2007; Wittenberg & Cock 2001).

Risk assessment schemes are science-based predictions which attempt to identify species that have not yet been introduced to a region but have a high likelihood of becoming invasive (Whitney & Gabler 2008). The implementation of risk assessment protocols produces net economic benefits (Keller et al. 2007), but only few countries, such as Australia and New Zealand, have implemented science-based risk assessment schemes as a screening routine to detect potential invasive species posing environmental and economic hazards.

In Spain, potential invasive plants not yet introduced in the country have not been identified, despite the Law of Natural Heritage and Biodiversity (42/2007), issued by the Spanish Environmental Ministry (http://www.boe.es/aeboe/), which mentions the need for prevention and management of those invasive species which threaten native species, natural habitats and economic resources. The present study aims to identify and rank non-native plant species that, if introduced, could potentially become invasive in Spain. This research is a basic tool to reinforce gardening, landscaping and plant trade regulations. We also provide information on the basic traits of these species in terms of taxonomy, origin, life form, and potential habitats to invade compared to invasive species that have already become established in the country (Sanz-Elorza et al. 2004).

Species ranking has been performed by applying two different risk assessment protocols: the Australian Weed Risk Assessment system (hereafter 'WRA'; Pheloung et al. 1999) and a Risk Assessment for Central Europe developed by Weber and Gut (2004) (hereafter, 'WG–WRA'). The first one has been selected due to its success and consistency in different regions (Gordon et al. 2008). The second protocol has been chosen because it has been developed specifically for Europe, albeit in central Europe, and uses a similar quantitative grading system than WRA. Both protocols rate species with an index as a measure of invasive potential, facilitating the comparison between them. We compared whether results were consistent among the two tests and discussed main differences.

Methods

Preselection of species

A plant data set was pre-selected for screening. This plant data set comprised all invasive plants of neighbouring countries and Mediterranean regions, but not yet present in Spain. All plant species listed as invasive in Portugal, France, Italy and in the Mediterranean Basin areas of Northern African countries, as well as, invasive species in other Mediterranean regions of the world (i.e., Chile, California, Australia and South Africa) were included in the list.

Although, Spain houses a heterogeneous climatic mosaic being oceanic in the North, alpine at high altitudes and somehow continental in the central plateau (but far less extreme than the Central Europe continental climate) most of its territory is influenced by Mediterranean climate (Ninyerola et al. 2000). Moreover, hot spots of invasive plant

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richness in Spain are localised in coastal areas with Mediterranean climate (Gassó et al. 2009; Pino et al. 2005) and very few are located in the central plateau. As Spanish invasive flora is mainly dominated by species of tropical and subtropical origin, most of them are presumably unable to complete their life-cycle through the winter months in cold areas with a continental climate (Casasayas 1990; Sanz-Elorza et al. 2004). These are the main reasons for choosing the Mediterranean climate as the most representative one of Spain in relation to invasive plant richness.

In order to compile the plant data set of potential invasive plants for Spain, online databases and scientific papers were consulted (Figueroa et al. 2004; Teillier et al. 2003; Vilà et al. 1999). The list was enlarged by plant species not present in natural areas of Spain listed in the IUCN's list of the 100 World's Worst Invasive Alien Species (http://www.issg.org/database), the DAISIE 100 of the worst invasive species of Europe (http://www.europe-aliens.org/) and the European and Mediterranean Plant Protection Organization (EPPO) quarantine lists (http://www.eppo.org/).

Subsequently, all species considered invasive in more than one country/region were selected for screening. A preliminary list of 80 species was obtained. For each species, the life form, the region of origin and the pathways of introduction were specified. Moreover, first European Nature Information System (EUNIS) category (http://eunis.eea.europa.eu/) habitat types where occurring, both in their native and introduced range, were gathered in order to identify which habitat types were more likely to be invaded. The EUNIS habitat classification system has been used in this study because it covers all types of natural and artificial habitats in Europe and it is widely used by European scientists and conservationists to standardise habitat types. Finally, the type of impact (i.e., ecological, socio-economic or human health impact) and the economic sector affected by the species: conservation; agriculture; cattle rising; recreation; fishing; navigation; health; irrigation and drainage was determined through literature review.

Risk assessment schemes description

The WRA is one of the best known protocols to date (Pheloung et al. 1999). It is a computer-based plant screening method producing a score for weediness or invasive potential, which can be converted to an entry recommendation for a specified taxon. It has been developed for and currently is in regulatory implementation in Australia and New Zealand. It consists of 49 questions divided into sections on biogeography, biology/ecology, and traits contributing to invasiveness (Pheloung 1995). Depending on the answer, each question is awarded between −3 and 5 points (mostly −1 to 1), and the final WRA score is the sum of points for all answered questions. This final score, ranging potentially from −14 (benign taxa) to 29 (maximum risk), leads to one of three outcomes: the species is accepted for introduction (<1 total points); rejected (>6 points); or recommended for further evaluation of invasive potential (1–6 points). A minimum of 10 answers are needed for a species to be evaluated; at least two in the biogeography section, two in traits section and six in biology/ecology. This risk assessment protocol has been chosen because it exhibits the highest accuracy when compared to others (Gordon et al. 2008); it has been validated against a large number of already introduced species and effectively discriminates invasive from non-invasive species (Gordon et al. 2008). This validation has been applied with success for Hawaii (Daehler & Carino 2000), the Pacific Islands (Daehler et al. 2004), the Czech Republic (Krivánek & Pyšek 2006), the Bonin (Ogasawara) Islands of Japan (Kato et al. 2006), the state of Florida, USA (Gordon et al. 2008) and Spain (Gassó et al. 2009). In our study, questions related to geography and climate, were modified to reflect the conditions of the target area. Suitability of species to Australian climate was changed to suitability to Mediterranean climate (question 2.01). Question 5.03 has also been modified: "Nitrogen fixing woody plants" to "Nitrogen fixing plants" as these are an important component of Spanish non-native flora, many such species being very abundant in ruderal, disturbed habitats (Sanz-Elorza et al. 2004). The test was answered following the instructions presented in Daehler et al. (2004).

For Europe, a few risk assessment systems have been developed. One of the best known is the European Plant Protection Organization (EPPO) Pest Risk Assessment Scheme that covers any pest organisms including plants and classifying them into pest recommended for regulation and plant quarantine, and pests possibly presenting a risk (http://www.eppo.org). This screening procedure primarily developed for plant and insect pests of agricultural habitats is based on expert judgment and does not rank species. Weber and Gut (2004) proposed a rating system to assess the invasion potential of non-native plant species according to the specific needs for central Europe. This risk assessment (WG–WRA) consists of a rating system

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that allocates scores to the species for biogeographical, ecological, and experience-linked aspects. The scores of 12 questions are totalled, and species are classified into "high risk" (28–39 points), "intermediate risk" (21–27 points), and "low risk" (3–20 points). This test has been validated with an overall accuracy of 65%.

In this study we used the WRA and the WG–WRA. Questions were answered with information gathered from scientific literature, Internet searches, floras, horticultural manuals and books. Climatic match was decided by determining the origin of the species and its distribution; following criteria developed by Daehler et al. (2004). The climatic match was considered high if the species was native to Mediterranean regions. It was intermediate if the species was not native to Mediterranean regions but was growing successfully in these regions and was considered low if the species was not native to Mediterranean regions and was not growing successfully in these regions.

Taxonomical information and geographical distribution data for Europe and the world were obtained from Flora Europaea online (http://www.rbge.org.uk/forms/fe.html), the online database from the Germplasm Resources Information Network (GRIN; http://www.ars-grin.gov/), the online database from the European Project DAISIE (http://www.europe-aliens.org/) and the information published by EPPO (http://www.eppo.org/). Ecological data were extracted from BioFlor (http://www.ufz.de/biolflor), Plants for a Future (2002) (http://www.comp.leeds.ac.uk/pfaf), species accounts from *Plantas Invasoras em Portugal* (http://www.uc.pt/invasoras), USDA Plants database (http://plants.usda.gov), International Survey of Herbicide Resistant Weeds (http://www.weedscience.org), Global Compendium of Weeds (http://www.hear.org/gcw), Global Invasive Species Database (http://www.issg.org/database/welcome), Weeds in Australia (http://www.weeds.gov.au), and Ecological Traits of New Zealand Flora (http://ecotraits.landcareresearch.co.nz).

Results and discussion

Characteristics of potential invaders

From the 80 potentially invasive species selected for further examination, the families with the highest number of species were Leguminosae (15%), followed by Asteraceae (10%) and Poaceae (6.3%). According to the database of the Atlas of invasive alien plants of Spain (Sanz-Elorza et al. 2004) updated with expertise information (Gasso et al. 2009) the most represented families of invasive species in Spain also belong to these families but in significantly different proportions ($\chi^2_9 = 45.2$; $p < 0.0001$): Asteraceae (18%), Poaceae (14%) and Leguminosae and Cactaceae (9%).

Regarding the life form, most of the screened plants are woody species (47%), followed by perennial herbs (24%), vines (11%), aquatic plants (10%) and annual herbs (8%). These results differ significantly from the growth habits of already existing invasive plants of Spain ($\chi^2_4 = 95.7$; $p < 0.0001$); being perennial herbs (44%) followed by annual herbs (29%), woody species (21%), vines (5%) and, finally, aquatic plants (2%) (Sanz-Elorza et al. 2004). In central Europe, woody plants have been reported as successful invaders compared to other plant groups (Kriváne k & Pyšek 2006). Thus, special care must be taken with this group of potential invasive species.

Twenty-eight percent of the potential invaders have originated in Central and/or South America, 21% in North America, 31% come from Asia, 12% from Africa and 8% from Australia (Figure 1). These proportions are significantly different from the ones for invasive species already present in Spain ($\chi^2_4 = 22.12$, $p < 0.001$; Sanz-Elorza et al. 2004). However, America is also the main origin of invasive species already present in Spain (58%), followed by Africa (16%), Asia (15%), Australia (6%) and Europe (3.5%).

Sixty-two percent of the screened species are ornamental and their main introduction pathway is through gardening. Only 12% and 11% are introduced through agriculture or unintentionally, respectively. The rest are used in aquaculture (6.5%),

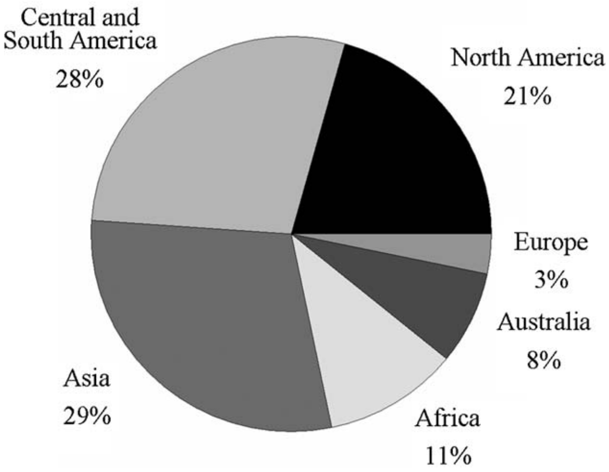

Figure 1. Origin of the 80 potentially invasive species for Spain.

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silviculture (4.6%) and restoration (3.7%). These proportions are significantly different to the ones obtained for invasive plants of Spain, for which the most common pathway of introduction is also gardening (50%) but it is followed by unintentional introduction (27%), agriculture (21%) and silviculture (3%) (Sanz-Elorza et al. 2004; $\chi^2_3 = 17.55$, $p < 0.001$). The fact that most potential invaders could be introduced deliberately rather than accidentally could reduce the risk of invasion given adequate resources and political will to ban their entrance (Hulme et al. 2008).

As for the EUNIS habitats the, heath land and scrubland habitats (F; 19%), followed by constructed, industrial and artificial habitats (J; 14%) and woodland and forest (G; 13%) are most at risk in terms of potential invasion. These results contrast significantly with the ones observed for invasive plants in Spain where most invaders occupy J habitats (61%) followed by agricultural habitats (I; 14%) (Sanz-Elorza et al. 2004; $\chi^2_8 = 278.37$, $p < 0.0001$). Instead, F habitats and woodlands (G) are the least invaded (less than 5%). In fact, Mediterranean woody habitats seem to be resistant to invasion Vilà et al. (2007). In Europe, woody habitats also contain a lower proportion of non-native plants than expected from the intensity of propagule pressure (Chytrý et al. 2008).

Finally, the hazards posed by these potentially invasive species could be mainly ecological (62%) and socio-economic (29%). Regarding the economic sectors affected, 50% of the potential invasive plants could impact on the nature conservation sector, 11% on the agricultural sector and 9% on cattle raising (9%).

Ranking potential invaders

All questions of the WG–WRA test could be answered and 82% (40 ± 0.45) of the questions from the WRA. Main gaps of knowledge correspond to reproductive characteristics of the screened plants (35%) and to dispersal mechanisms (25%). According to both tests most screened species are potentially invasive in Spain (Appendix I). Nine species, though, showed scores equal or lower than six in the WRA test, which suggest that their invasive potential requires further evaluation (Figure 2).

The species can be divided into three class distributions according to their score (Figure 3). Most screened species have intermediate values in both tests (Figure 3). In fact, there is a positive relationship between the values from the two risk assessment tests, showing that both tests ranked species in a similar way ($y = 0.78x+14.16$; $r^2 = 0.97$; Figure 4). However, 39 species (37%) modified their position over the three class distributions; 26 have higher risk class distribution in the WG–WRA than in the WRA and three have lower risk in the WG–WRA (Appendix I). Nonetheless, these differences within the positions of the species within the two tests can be explained by the fact that class distributions of the WRA test have been chosen arbitrarily and no thresholds have been set up by the authors designing the protocols (Pheloung et al. 1999).

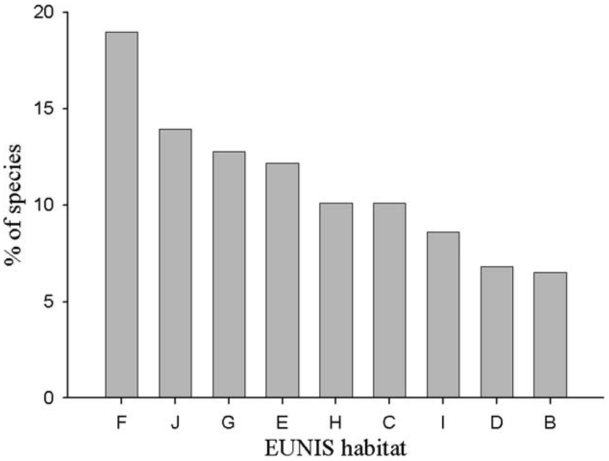

Figure 2. Potential EUNIS habitats (http://eunis.eea.europa.eu/) that could be invaded in Spain by 80 potentially invasive species. F: Heath land and scrubland tundra; J: Constructed, industrial and other artificial habitats; G: Woodland, forest and other wooded land; E: Grasslands and lands dominated by forbs, mosses or lichens; H: Inland unvegetated or sparsely vegetated habitats; C: Inland surface waters; I: Regularly or recently cultivated agricultural, horticultural and domestic habitats; D: Mires, bogs and fens; B: Coastal habitats.

Chromolaena odorata (L.) R.M. King and H. Rob. (Fam. Asteraceae) obtained the highest score in both tests and, therefore, is the species with the highest risk to become invasive in Spain if introduced. *C. odorata* is a fast-growing perennial shrub, native to South America and Central America. It has been introduced mainly as an ornamental plant, but also accidentally, in many tropical regions of Asia, Africa and the Pacific and in the Mediterranean areas of Australia and South Africa, where it is a very invasive weed. Indeed, it is considered one of the 100 worst invasive species of the world by the IUCN (http://www.issg.org/database/welcome/). It forms dense stands that prevent the establishment of other plant species and is an aggressive competitor with allelopathic effects (Onwugbuta-Enyi 2001). It is also a nuisance weed in agricultural lands and commercial tree plantations, thus, preventive measures should be

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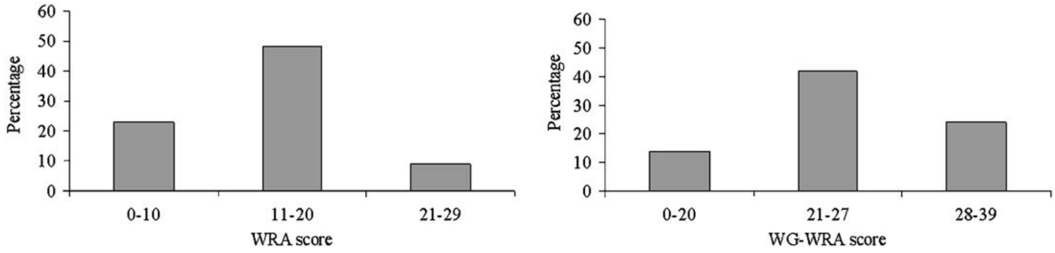

Figure 3. Class distribution of scores of 80 potentially invasive species in Spain according to the WRA and to the WG–WRA system.

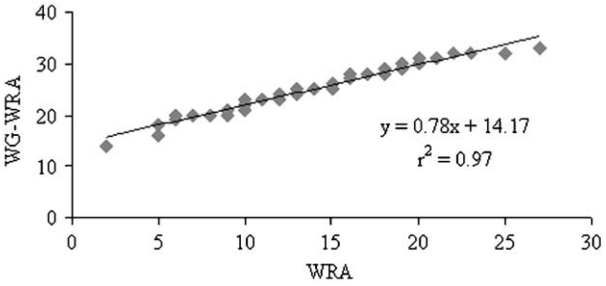

Figure 4. Relationship between the scores of the 80 potentially invasive species for Spain according to their WRA and WG–WRA score.

taken to avoid its naturalisation and trade (Roder et al. 1995).

The class distribution with the highest scores include five aquatic species: *Cabomba caroliniana* A. Gray, *Hydrocotyle ranunculoides* L.f.; *Salvinia molesta* D. Mitch, *Ludwigia peploides* (Kunth) P.H. Raven; and *Alternanthera philoxeroides* (Mart.) Griseb., confirming their great capacity for invasion, their devastating impacts, not only environmental but also economic, and their complicated and costly control (Pimentel et al., 2005). Aquatic plants are very easy to purchase and there is no control over their use and trade, therefore, early detection efforts should be put in place to detect the entrance of these species in the country.

Main ranking differences among species in the two tests can be a consequence of different information required to answer the questionnaires. Both tests give a relevant importance to the distribution of the target species in other regions (e.g., Scott & Panetta 1993) and to climate matching (Bomford et al. 2005; Thuiller et al. 2005). However, only the WRA test incorporates the historical pest status of the target plant in other regions. The invasive-elsewhere criterion is generally considered very important for the assessment of potentially invasive species (Reichard & Hamilton 1997; Rejmanek et al. 2005).

The potential impacts over agriculture and the existence of weedy congeners are taken into account by both tests but the WRA test also considers other economic impacts such as negative effects on recreation, amenity, tourism, etc. Moreover, the WRA test also allows, by splitting the total score of the WRA, an estimation of whether a plant is more likely to impact on agriculture or on natural ecosystems, which can also assist environmental managers in making recommendations. Almost all potential invasive species screened with the WRA (97.5%) were regarded as both environmental and agricultural weeds and only 2.5% were environmental weeds only.

Regarding biological traits, life form, vegetative growth, seed viability, type of reproduction and dispersal mode are included in both tests. While the WRA test gives higher risk to aquatic plants and grasses, the WG–WRA test also confers high scores to woody perennial species, as woody plants have been reported as successful invaders in central Europe, where the protocol was developed (Kriválnek & Pyšek 2006). Undesirable traits like spinescence, toxicity and increment of fire hazard are only incorporated in the WRA test and they fit very well with traits that can have an impact on pasture and fire regime, two of the most relevant features shaping the vegetation of Mediterranean type-ecosystems (Di Castri & Mooney 1973). The WRA also includes evolutionary considerations such as the hybridising potential of the invader, a trait which has been shown to be relevant to reinforce invasion (Vilà et al. 1998). Finally, only the WRA scheme mentions plant persistence attributes such as persistent seed bank or high resprout capacity, which can be an indirect indicator of the management effort required (Burch & Zedaker 2003; Hiebert & Stubbendieck 1993).

In this study we have tested whether invasive species of other Mediterranean regions would become invasive if introduced to Spain. However, another comprehensive list of potential invasive species could be obtained considering all native species to the rest of Mediterranean regions of the world. Given that similarity in climate between native and target regions has long been recognised

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as a basic requirement for a successful invasion (Bomford et al. 2005; Scott & Panetta 1993; Thuiller et al. 2005), this approach would also be a useful tool to identify potential invasive plants for Spain.

Conclusions

The rapidly increasing number of non-native species and their tremendous costs to the environment and society (Pimentel et al., 2005) suggests an urgent requirement for decision-making tools for the management of plant invasions and the regulation of plant trade in order to diminish the risks of new introductions (Sandlund et al. 1999). Risk assessment schemes are valuable tools to diminish the risk of invasion and to concentrate resources on tackling the pathways relevant to those species with higher risk of invasion. In fact, they are the first step towards developing restrictive policies regarding the introduction of novel species. This does not involve denying the agriculturist and horticulturist the option to provide their customers with new plants. It does mean that introduced plant species would only be allowed to be imported if they have not demonstrated capacity to become invasive. If a species is judged to have high invasive potential, rejection for introduction is the prudent policy. The high cost: benefit ratio associated with invasive species risk assessments (i.e., cost of allowing an invasion: benefit of allowing introduction of a presumed non-invasive) means the use of a very conservative approach should be recommended. Besides, risk assessment schemes could also be valuable for the development of lists of non-native plant species that can be permitted to be imported because it has been demonstrated that they pose a low threat of becoming invasive.

The two risk assessment schemes used in this study identify a wide range of potential invasive species not yet introduced to Spain and that are likely to cause economic and environmental impacts. The fact that two different methods ranked species in a similar way increases the probability to identify invasive plants correctly. The species with higher scores on the risk assessment should be prohibited or kept out of trade related pathways in which species are specifically marketed such as aquarium trade, gardening and seed purchase. However, it is important to take into account that non-native plants can be invasive in one habitat of their introduced range but not in another, depending on particular habitat properties such as disturbance regime, microclimate/soil properties or propagule pressure (Chytrý et al. 2008; Thompson et al. 1995). Therefore, besides the listed and ranked species presented in this paper more could be invasive to the country. As a consequence, although policies would need to be implemented at the national level, local analyses within that larger area are also necessary.

Acknowledgments

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Appendix I

WRA and WG–WRA scores for 80 potential invasive species in Spain

Non-native plant	WRA score	Non-native plant	WG–WRA score
Chromolaena odorata (L.) R.M. King & H. Rob.	27	*Alternanthera philoxeroides* (Mart.) Griseb.	33
Cabomba caroliniana A. Gray	27	*Chromolaena odorata* (L.) R.M. King & H. Rob.	33
Hydrocotyle ranunculoides L. f.	25	*Salvinia molesta* D. Mitch.	32
Salvinia molesta D. Mitch.	23	*Prosopis glandulosa* Torr	32
Hydrilla verticillata (L.f.) Royle	23	*Cortaderia jubata* (Lem.) Stapf	32

Prosopis glandulosa Torr	22	*Heracleum mantegazzianum* Sommier & Levier	32
Cryptostegia grandiflora R.Br.	22	*Tamarix ramosissima* Ledeb.	32
Ludwigia peploides (Kunth) P.H. Raven	21	*Acacia mearnsii* De Wild.	31
Alternanthera philoxeroides (Mart.) Griseb.	21	*Panicum maximum* Jacq.	31
Nassella tenuissima (Trin.) Barkworth	20	*Tamarix aphylla* (L.) Karst.	31
Cortaderia jubata (Lem.) Stapf	20	*Cabomba caroliniana* A. Gray	30
Panicum maximum Jacq.	19	*Ludwigia peploides* (Kunth) P.H. Raven	30
Elodea nuttallii (Planch.) H. St. John	19	*Nassella tenuissima* (Trin.) Barkworth	30
Crassula helmsii (Kirk) Cockayne	19	*Acacia nilotica* (L.) Delile	30
Asparagus asparagoides (L.) Druce	19	*Cryptostegia grandiflora* R.Br.	29
Acacia mearnsii De Wild.	19	*Asparagus asparagoides* (L.) Druce	29
Opuntia aurantiaca Lindl.	18	*Mimosa pigra* L.	29
Mimosa pigra L.	18	*Hedychium gardnerianum* Sheppard ex Ker Gawl.	29
Lupinus arboreus Sims	18	*Mikania micrantha* Kunth	29
Lagarosiphon major (Ridl.) Moss	18	*Lagarosiphon major* (Ridl.) Moss	28
Heracleum mantegazzianum Sommier & Levier	18	*Hydrocotyle ranunculoides* L. f.	28
Lysichiton americanus Hultén & H. St. John	17	*Elodea nuttallii* (Planch.) H. St. John	28
Clidemia hirta D. Don	17	*Lupinus arboreus* Sims	28
Watsonia bulbillifera Matthews & L. Bolus	16	*Pueraria lobata* (Willd.) Ohwi	28
Tamarix ramosissima Ledeb.	16	*Hydrilla verticillata* (L.f.) Royle	27
Tamarix aphylla (L.) Karst.	16	*Alhagi pseudalhagi* (M. Bieb.) Desv.	27
Hedychium gardnerianum Sheppard ex Ker Gawl.	16	*Ligustrum sinense* Lour.	27
Gunnera tinctoria (Molina) Mirb.	16	*Berberis thunbergii* DC.	27
Cotoneaster franchetii Boiss.	16	*Rosa rugosa* Thunb.	27
Rubus ellipticus Sm.	15	*Crassula helmsii* (Kirk) Cockayne	26
Pueraria lobata (Willd.) Ohwi	15	*Lysichiton americanus* Hultén & H. St. John	26
Miscanthus sinensis Anderss.	15	*Gunnera tinctoria* (Molina) Mirb.	26
Miconia calvescens DC.	15	*Rubus ellipticus* Sm.	26
Epilobium ciliatum Raf.	15	*Reynoutria sachalinensis* (F. Schmidt) Nakai	26
Cereus martinii Labour.	15	*Opuntia aurantiaca* Lindl.	25
Acacia nilotica (L.) Delile	15	*Dalbergia sissoo* Roxb. ex DC.	25
Parthenium hysterophorus L.	14	*Leptospermum laevigatum* F. Muell.	25
Mikania micrantha Kunth	14	*Passiflora subpeltata* Ortega	25
Triadica sebifera (L.) Small	13	*Reynoutria x bohemica* Chrtek & Chrtková	25
Sesbania punicea (Cav.) Benth.	13	*Clidemia hirta* D. Don	24
Ligustrum sinense Lour.	13	*Cotoneaster franchetii* Boiss.	24
Dalbergia sissoo Roxb. ex DC.	13	*Cereus martinii* Labour.	24
Chorispora tenella (Pall.) DC.	13	*Epilobium ciliatum* Raf.	24
Celtis sinensis Pers.	13	*Miconia calvescens* DC.	24
Alhagi pseudalhagi (M. Bieb.) Desv.	13	*Miscanthus sinensis* Anderss.	24
Acroptilon repens (L.) DC.	13	*Triadica sebifera* (L.) Small	24
Psidium cattleianum Sabine	12	*Coreopsis lanceolata* L.	24
Passiflora subpeltata Ortega	12	*Psidium cattleianum* Sabine	24
Leptospermum laevigatum F. Muell.	12	*Spathodea campanulata* P. Beauv.	24
Heracleum sosnowskyi Mandenova	12	*Watsonia bulbillifera* Matthews & L. Bolus	23
Berberis thunbergii DC.	12	*Celtis sinensis* Pers.	23

Acacia paradoxa DC.	12	*Heracleum sosnowskyi* Mandenova	23
Spathodea campanulata P. Beauv.	11	*Sesbania punicea* (Cav.) Benth.	23
Reynoutria x bohemica Chrtek & Chrtková	11	*Acacia paradoxa* DC.	23
Reynoutria sachalinensis (F. Schmidt) Nakai	11	*Cecropia peltata* L.	23
Coreopsis lanceolata L.	11	*Melaleuca quinquenervia* (Cav.) S.T. Blake	23
Cinnamomum camphora (L.) J. Presl	11	*Sphagneticola trilobata* (L.) Pruski	23
Sphagneticola trilobata (L.) Pruski	10	*Passiflora edulis* Sims	23
Rosa rugosa Thunb.	10	*Acroptilon repens* (L.) DC.	22
Melaleuca quinquenervia (Cav.) S.T. Blake	10	*Cinnamomum camphora* (L.) J. Presl	22
Eugenia uniflora L.	10	*Hakea salicifolia* (Vent.) B.L. Burtt	22
Cinchona pubescens Vahl	10	*Amelanchier spicata* (Lam.) K. Koch	22
Cecropia peltata L.	10	*Solidago nemoralis* Ait.	22
Aristolochia elegans Mast.	10	*Ardisia elliptica* Thunb.	21
Ardisia elliptica Thunb.	10	*Aristolochia elegans* Mast.	21
Humulus scandens (Lour.) Merr.	9	*Spartina anglica* C.E. Hubb.	21
Dipogon lignosus (L.) Verdc.	9	*Parthenium hysterophorus* L.	20
Hakea salicifolia (Vent.) B.L. Burtt	8	*Cinchona pubescens* Vahl	20
Solidago nemoralis Ait.	7	*Eugenia uniflora* L.	20
Senna septemtrionalis (Viv.) H.S. Irwin & Barneby	7	*Humulus scandens* (Lour.) Merr.	20
Amelanchier spicata (Lam.) K. Koch	7	*Echinocystis lobata* (Michx.) Torr. & A. Gray	20
Spartina anglica C.E. Hubb.	6	*Hiptage benghalensis* (L.) Kurz	20
Rivina humilis L.	6	*Syzygium cumini* (L.) Skeels	20
Passiflora edulis Sims	6	*Solanum seaforthianum* Andrews	19
Syzygium cumini (L.) Skeels	5	*Dipogon lignosus* (L.) Verdc.	18
Solanum seaforthianum Andrews	5	*Senna septemtrionalis* (Viv.) H.S. Irwin & Barneby	18
Hiptage benghalensis (L.) Kurz	5	*Bidens connata* Muhl. ex Willd.	18
Echinocystis lobata (Michx.) Torr. & A. Gray	5	*Pinus elliottii* Engelm.	18
Bidens connata Muhl. ex Willd.	5	*Rivina humilis* L.	16
Pinus elliottii Engelm.	2	*Chorispora tenella* (Pall.) DC.	14

References

Bomford, M., Kraus, F., Braysher, M., Walter, L., & Brown, L. (2005). *Risk assessment model for the import and keeping of exotic reptiles and amphibians*. Canberra, ACT, Australia: Bureau of Rural Sciences.

Burch, P. L., & Zedaker, S. M. (2003). Removing the invasive tree *Ailanthus altissima* and restoring natural cover. *Journal of Arboriculture*, *29*(1), 18–24.

Burke, M. J. W., & Grime, J. P. (1996). An experimental study of plant community invasibility. *Ecology*, *77*, 776–790.

Casasayas, T. (1990). Widespread adventive plants in Catalonia. In F. Di Castri, A. J. Hansen, & M. Debussche (Eds.), *Biological invasions in Europe and the Mediterranean basin* (pp. 85–104). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Chytrý, M., Jarošik, W., Pyšek, P., Hájek, O., Knollová, I., Tichí, L., & Danihelka, J. (2008). Separating habitat invasibility by alien plants from the actual level of invasion. *Ecology*, *89*(6), 1541–1553.

Daehler, C. C., & Carino, D. A. (2000). Predicting invasive plants: Prospects for general screening system based on current regional models. *Biological Invasions*, *2*, 93–102.

Daehler, C. C., Denslow, J., Ansari, S., & Kuo, H.-C. (2004). A risk-assessment system for screening out invasive pest plants from Hawaii and other Pacific Islands. *Conservation Biology*, *18*, 360–368.

Di Castri, F., & Mooney, H. A. (1973). *Mediterranean-type ecosystems: Origin and structure*. Berlin/Heidelberg/New York: Springer.

Duncan, R. P., Blackburn, T. M., & Sol, D. (2003). The ecology of bird introductions. Annual reviews of ecology. *Evolution and Systematics*, *34*, 71–98.

Figueroa, J. A., Castro, S. A., Marquet, P. A., & Jaksic, F. M. (2004). Exotic plant invasions to the Mediterranean

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region of Chile: Causes, history and impacts. *Revista Chilena de Historia Natural*, *77*, 465–483.

Gassó, N., Sol, D., Pino, J., Dana, E. D., Lloret, F., Sanz-Elorza, M., et al. (2009). Exploring species attributes and site characteristics to assess plant invasions in Spain. *Diversity and Distributions*, *15*, 50–58.

Gassó, N., Basnou, C., Vilà, M. (2009). Predicting plant invaders in the mediterranean through a weed risk assessment system. Biological Invasions, in press, doi:10.1007/s10530-009-9451-2.

Goodwin, B. J., Mcallister, A. J., & Fahrig, L. (1999). Predicting invasiveness of plant species based on biological information. *Conservation Biology, 13*, 422–426.

Gordon, D. R., Onderdonk, D. A., Fox, A. M., & Stocker, R. K. (2008). Consistent accuracy of the Australian weed risk assessment system across varied geographies. *Diversity and Distributions*, *14*, 234–242.

Groves, R. H., Panetta, FD., & Virtue, J. G. (2001). *Weed risk assessment*. Collingwood, Australia: CSIRO Publishing.

Hiebert, R. D., Stubbendieck, J. (1993). Handbook for ranking exotic plants for management and control. Natural Resources Report 93/08, US Department of the Interior, National Park Service, USA.

Hulme, P. E., Bacher, S., Kenis, M., Klotz, S., Kühn, I., Minchin, D., et al. (2008). Grasping at the routes of biological invasions: A framework for integrating pathways into policy. *Journal of Applied Ecology, 45*, 403–414.

Kato, H., Hata, K., Yamamoto, H., & Yoshioka, T. (2006). Effectiveness of the weed risk assessment system for the Bonin Islands. In F. Koike, M. N. Clout, M. Kawamichi, M. De Poorter, & K. Iwatsuki (Eds.), *Assessment and control of biological invasion risk* (pp. 65–72). Gland, Switzerland: Shoukadoh Book Sellers, and IUCN.

Keller, R. P., Lodge, D. M., & Finnoff, D. C. (2007). Risk assessment for invasive species produces net bioeconomic benefits. *Proceedings of the National Academy of Sciences*, *104*, 203–207.

Křivánek, M., & Pyšek, P. (2006). Predicting invasions by woody species in a temperate zone: A test of three risk assessment schemes in the Czech Republic (Central Europe). *Diversity and Distributions*, *12*, 319–327.

Levine, J. M., Vilà, M., D'Antonio, C. M., Dukes, J. S., Grigulis, K., & Lavorel, S. (2003). Mechanisms underlying the impacts of exotic plant invasions. *Proceedings Royal Society of London B*, *270*, 775–781.

Lonsdale, W. M. (1999). Global patterns of plant invasions and the concept of invasibility. *Ecology, 80*, 1522–1536.

Mack, R. N., Simberloff, D., Lonsdale, W. M., Evans, H., Clout, M., & Bazzaz, F. A. (2000). Biotic invasions: Causes, epidemiology, global consequences and control. *Ecological Applications*, *10*, 689–710.

McNeely, J., Mooney, H. A., Neville, L. E., Schei, P. J., & Waage, J. K. (2001). *Global strategy on invasive alien species*. Cambridge: IUCN.

Mooney, H. A., & Hobbs, R. J. (2000). *Invasive species in a changing world*. Washington, DC: Island Press.

Ninyerola, M., Pons, X., & Roure, J. M. (2000). A methodological approach of climatological modelling of air temperature and precipitation through GIS techniques. *International Journal of Climatology, 20*, 1823–1841.

Onwugbuta-Enyi, J. (2001). Allelopathic effects of *Chromolaena Odorata* L. (R. M. King and Robinson – (awolowo plant)) toxin on tomatoes (*Lycopersicum esculentum* mill). *Journal of Applied Sciences & Environmental Management*, *5*(1), 69–73.

Panetta, F. D., & Scanlan, J. C. (1995). Human involvement in the spread of noxious weeds: What plants should be declared and when should control be enforced? *Plant Protection Quarterly, 10*, 69–74.

Pheloung, P. C. (1995). Determining the weed potential of new plant introductions to Australia. Perth, Western Australia: Agriculture Protection Board Report, West Australian Department of Agriculture.

Pheloung, P. C., Williams, P. A., & Halloy, S. R. (1999). A weed risk assessment model for use as a biosecurity tool evaluating plant introductions. *Journal of Environmental Management*, *57*, 239–251.

Pimentel, D., Zuniga, R., & Morrison, D. (2005). Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecological Economics*, *52*, 273–288.

Pino, J., Font, X., Carbó, J., Jové, M., & Pallarès, L. (2005). Large-scale correlates of alien plant invasion in Catalonia (NE of Spain). *Biological Conservation*, *122*, 339–350.

Pyšek, P., & Jarosík, V. (2005). Residence time determines the distribution of alien plants. In Inderjit (Ed.), *Invasive plants: Ecological and agricultural aspects* (pp. 77–96). Switzerland: Birkhauser Verlag.

Pyšek, P., & Richardson, D. M. (2007). Traits associated with invasiveness in alien plants: Where do we stand? In W. Nentwig (Ed.), *Ecological studies: Biological invasions* (pp. 97–125). Berlin, Heidelberg: Sringer.

Reichard, S. H., & Hamilton, C. W. (1997). Predicting invasions of woody plants introduced into North America. *Conservation Biology, 11*, 193–203.

Rejmánek, M., & Richardson, D. M. (1996). What attributes make some plant species more invasive? *Ecology, 77*, 1655–1661.

Rejmánek, M., Richardson, D. M., Higgins, S. I., Pitcairn, M. J., & Grotkopp, E. (2005). Ecology of invasive plants: State of the art. In H. A. Mooney, R. M. Mack, J. A. McNeeley, L. Neville, P. Schei, & J. Waage (Eds.), *Invasive alien species: Searching for solutions* (pp. 104–161). Washington, DC: Island Press.

Richardson, D. M., & Pyšek, P. (2006). Plant invasions: Merging the concepts of species invasiveness and community invasibility. *Progress in Physical Geography, 30*, 409–431.

Roder, W., Phengchanh, S., Keoboualapha, B., & Maniphone, S. (1995). *Chromolaena odorata* in slash-and-burn rice systems of Northern Laos. *Agroforestry Systems*, *31*, 79–92.

Please cite this article as: Andreu, J., & Vilà, M. Risk analysis of potential invasive plants in Spain. *Journal for Nature Conservation*, (2009), doi:10.1016/j.jnc.2009.02.002

Sandlund, O. T., Schei, P. J., & Viken, A. (1999). *Invasive species and biodiversity management*. Dordrecht: Kluwer Academic Publishers.

Sanz-Elorza, M., Dana, E. D., & Sobrino, E. (2004). *Atlas de las plantas alóctonas invasoras de España*. Madrid: Dirección General para la Biodiversidad.

Scott, J. K., & Panetta, F. D. (1993). Predicting the Australian weed status of southern African plants. *Journal of Biogeography*, *20*, 87–93.

Settele, J., Hammen, V., Hulme, P., Karlson, U., Klotz, S., Kotarac, M., et al. (2005). ALARM – assessing LArge-scale environmental risks for biodiversity with tested methods. *GAIA – Ecological Perspectives in Science, Humanities, and Economics*, *14/1*, 69–72.

Teillier, S., Rodríguez, R., & Serra, M. T. (2003). Lista preliminar de plantas leñosas, alóctonas, asilvestradas en Chile Continental. *Chloris Chilensis*, *6*(2) (http://www.chlorischile.cl).

Thompson, K., Hodgson, J. G., & Rich, T. C. G. (1995). Native and alien invasive plants: More of the same? *Ecography*, *18*, 390–402.

Thuiller, W., Richardson, D. M., Pysek, P., Midgley, G. F., Hughes, G. O., & Rouget, M. (2005). Niche-based modelling as a tool for predicting the risk of alien plant invasions at a global scale. *Global Change Biology*, *11*, 2234–2250.

Vilà, M., Meggaro, Y., & Weber, E. (1999). Preliminary analysis of the naturalized flora of northern Africa. *Orsis*, *14*, 9–20.

Vilà, M., Weber, E., & D'Antonio, C. M. (1998). Flowering and mating system in hybridizing *Carpobrotus* (Aizoaceae) in coastal California. *Canadian Journal of Botany – revue Canadienne de Botanique*, *76*(7), 1165–1169.

Vilà, M., Pino, J., & Font, X. (2007). Regional assessment of plant invasions across different habitat types. *Journal of Vegetation Science*, *18*(1), 35–42.

Vitousek, P. M., D'Antonio, C. M., Loope, L. L., Rejmanek, M., & Westerbrooks, R. (1997). Introduced species: A significant component of human-caused global change. *New Zealand Journal of Ecology*, *21*(1), 1–16.

Weber, E., & Gut, D. (2004). Assessing the risk of potentially invasive plant species in central Europe. *Journal for Nature Conservation*, *12*, 171–179.

Whitney, K. D., & Gabler, C. A. (2008). Rapid evolution in introduced species, 'invasive traits' and recipient communities: Challenges for predicting invasive potential. *Diversity and Distributions*, *14*(4), 569–580.

Williamson, M. H. (1999). Invasions. *Ecography*, *22*, 5–12.

Wittenberg, R., & Cock, M. J. W. (2001). *Invasive alien species: A toolkit of best prevention and management practices*. Wallingford, Oxon: CAB International.

Please cite this article as: Andreu, J., & Vilà, M. Risk analysis of potential invasive plants in Spain. *Journal for Nature Conservation*, (2009), doi:10.1016/j.jnc.2009.02.002