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# Challenge of weed risk assessment (WRA) for ecological restoration in China: The case of Rhus typhina L. and the new officially released weed risk assessment system

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RECENT STUDY ON PLANT-SOIL INTERACTIONS IN CHINA - PART I

# Challenge of weed risk assessment (WRA) for ecological restoration in China: The case of *Rhus typhina* L. and the new officially released weed risk assessment system

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**Abstract**
China has conducted many ecological restoration projects to alleviate environmental degradation, with numerous alien species having good adaptability widely used for fast effect. However, unsuitable plant selection may bring negative impacts and even cause biological invasion. Weed risk assessment (WRA) is therefore indispensable, yet it is often contentious especially concerning those species that has been widely utilized before weedy attributes were noted. In this paper, we take *Rhus typhina* L. as an example to illustrate how scientific researches and social factors can influence the evaluation of alien species and cause challenge to WRA. The evaluation of this species is not only a pure scientific issue but also influenced by many factors such as the introduction history, current utilization status in afforestation, and divergent underlying values varying through persons and sectors. These factors determined the kind of data to be assessed, which lead to different evaluations, therefore, causing challenge to its WRA. We further examined newly officially released WRA system in China from the invasion biology viewpoint, arguing that it had some major flaws in design and validation and need much improvement. Considering the human dimension and biological characters together, we suggest that the "black list" and "green list" approaches with rigorous expert assessment should be adopted simultaneously in alien species management in China.

**Keywords:** *Challenge, China, invasive species, weed risk assessment,* Rhus typhina *L*

## Introduction

Afforestation has been considered as one of the main methods to restore the degraded ecosystem in China and worldwide (Stanturf & Madsen 2002; Zhang et al. 2002; Spanjol et al. 2009), especially in those bare lands or wind–water erosion regions (Wang et al. 2012a). However, the afforestation practice often simply transformed the degraded sites, even many natural forests, into plantations, which decreased the forest complexity and biodiversity (Magnussen et al. 2007; Ciancio & Nocentini 2011). Another more important issue is the utilization of some alien species in afforestation for fast effect due to their good adaptability to harsh site conditions (Wang et al. 2012b). While these alien species could increase vegetation cover significantly, they may bring some negative effects. For instance, in the Loess Plateau, China, afforestation with introduced species such as alfalfa (*Caragana korshinskii* L.) or korshinsk peash-rub (*Medicago sativa* kom.) has adversely affected physical properties of the soil (Wang et al. 2012b). The high cover of dry exotic litter has also reduced the amount of bryophyte and lichen cover on sand dunes

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in Sardinia, Italy (Zedda et al. 2010). More serious problem bundle with using alien species is the risk of biological invasion. Good adaptability of some alien species in harsh environment may also make them grow or spread aggressively, thereby becoming invasive, causing apparent damage or pose potential threats to species, ecosystems, or economy (International Union for the Conservation of Nature [IUCN] 1999; McNeely et al. 2001). Therefore, while biodiversity conservation and management of the natural or the existing old-growth forests having been paid high attention (Liira & Kohv 2010; Horvath et al. 2012; Kalajnxhiu et al. 2012; Keenan & Read 2012; Minissale & Sciandrello 2013; Palombo et al. 2013), more care is needed in plant selection when afforesting for ecological restoration. Weed risk assessment (WRA) is therefore indispensable to eliminate the possible negative impact.

However, it is often contentious when assessing the weed risk of a specific species, for many plants with invasive characters are regarded as useful or desirable by at least some sectors of the community (Roberts et al. 2011). Such a problem becomes more complicated when concerning those species that have been widely utilized before their weedy attributes were noted. The assessment of *Rhus typhina* L. (staghorn sumac) in China is a good example. This North American native plant has been utilized widely in afforestation since its introduction in China (Pan & You 1994). However, it was queried for its invasiveness in the past decade, thereby evoking wide debate on its weed risk (Wang et al. 2008). How to evaluate and manage this kind of species is still puzzling the managers and the nonspecialist public.

Different perceptions on a specific alien species were due to not only various viewpoints on its ecological impacts but also influenced by social factors, as the cases of Australian acacias (Carruthers et al. 2011; Kull et al. 2011; Low 2012) and buffel grass (Friedel et al. 2011; Marshall et al. 2011). However, though sharp disagreements were displayed on many alien spices in China (Pan et al. 2006; Wang et al. 2006), most researches have mainly focused on their ecological impacts. Studies were seldom conducted with scientific and social factors considered together to analyze why the disagreements last. Here, we take *R. typhina* as an example to exemplify how scientific researches and social factors can influence the evaluation of alien species and cause challenges to WRA in China. We summarized the evidence for and against *R. typhina* in the dispute with the relevant social factors examined as well, to analyze the reasons why the evaluations of this alien species are so different. Given the severe problem of biological invasion in China (Ding et al. 2008; Xu & Qiang 2011), we further examined the appropriateness of the newly released WRA system by State Forestry Administration of China. Based on the analysis, we proposed some recommendations on WRA and management of alien species in China. Considering that there are many alien species that are contentious as *R. typhina*, we think this study could benefit to set up a helpful reference for alien species management in some countries like China.

## Utilization of and dispute on *R. typhina* in China

### *Extension of* R. typhina *in China*

*Rhus typhina* is a large shrub or small tree native to the eastern USA and north Canada. It is widespread in its native range and thrives in various habitats, including old field margins, roadsides, and fence rows (Uva et al. 1997). In 1959, this species was introduced to China by the Botanic Garden of Institute of Botany, Chinese Academy of Science. As it could grow vigorously without any cultivation help even under heavy drought when cultivated in the botanic garden, the introducer believed it could retain water and soil effectively and began to spread its seeds to many provinces of North China since 1974 (Pan & You 1994). Through the afforestation practice in sterile mountainous areas, its fast-growing ability under environmental stresses was proved and afterwards recommended to a wide extension by botanists and departments of forestry or other organs of the government (e.g. Highway Management Bureau). In the following 30 years, the vigorous extension has finally helped *R. typhina* spreading into 21 provinces in China (Figure 1).

### *Evocation of the dispute*

The initial query on *R. typhina* emerged in 2002. When an article concerning the invasive plants in Beijing was published (Liu et al. 2002), *Rhus typhina* was listed as invasive. However, this information did not get wide attention in the next 2 years for lack of concrete exposition. Public awareness was not brought until a newspaper article was published in *Science and Technology Daily* (a mainstream newspaper in China) on February 7, 2004 (Zheng 2004). In that paper, the reporter cautioned the potential invasion of *R. typhina* when this plant was chosen as one of the main afforestation species in Beijing Olympic construction, according to its ability to form dense thickets and the negative impact on plant diversity. Many newspapers reprinted this article and subsequently evoked wide discussion. Though the controversy has lasted for a decade, disagreements are still sharply displayed among researchers, administrators, and the public. On the one hand, many researchers listed *R. typhina* as invasive or urged caution (Zhang et al. 2004; Wang et al. 2008,

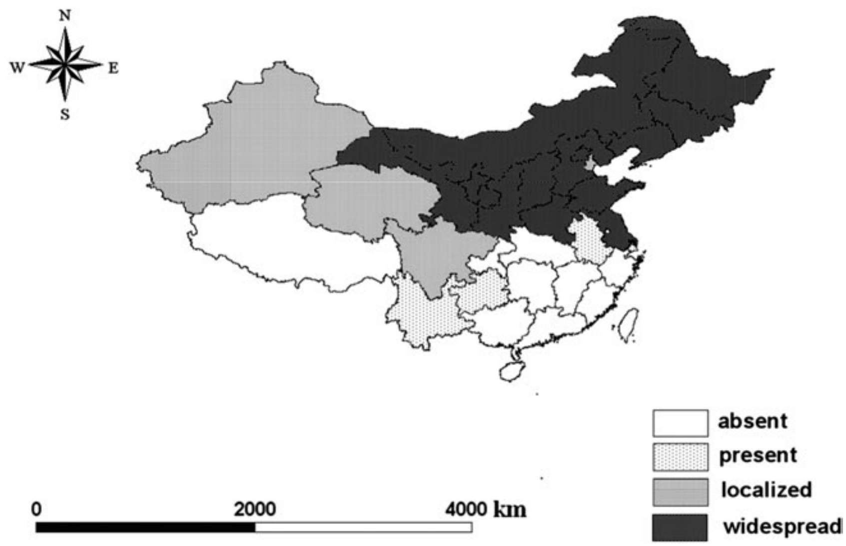


Figure 1. Distribution of *R. typhina* in China. Absent means no distribution or not documented of *R. typhina* in the province; present means distributed in only one district in a province; localized means distributed in two to five districts in a province; widespread means distributed in more than five districts in a province. Data from literatures searched in the electronic database of China National Knowledge Infrastructure and ISI Web of Science as well as the Internet.

2011; Weber et al. 2008; Zhang et al. 2009). On the other hand, the species is still being advocated and used widely in many regions of north China.

### *Dispute on* R. typhina *and the corresponding evidence*

As any species, native or nonnative, could have both positive and negative effects, different sections of the community may view the same species very differently (Carruthers et al. 2011; Roberts et al. 2011). As for the case of *R. typhina* in China, advocators favored this species mainly based on its good ability to grow at, or "green", the bare hills and harsh environment. They denied the weed risk of *R. typhina* according to the investigation in Beijing's mountainous area, where the growth and spread were controlled by poor site conditions (Zhang et al. 2005). As *R. typhina* is identified as shade intolerant in its native range (The PLANTS Database 2012), they thought this species could not become dominant even though it could invade the local arboreal community (Zhang et al. 2005; Chen et al. 2006). Furthermore, they deduced that *R. typhina* may promote tree seedling establishment through the suppression to shrub and herb based on some native tree seedlings (49 seedlings in 132 $m^2$ with majority no more than 30 cm) emerged under *R. typhina* canopy (Zhang et al. 2005). Therefore, they argued that *R. typhina* did not threaten the natural or semi-natural arboreal ecosystem and thereby was not invasive. Emphasized on the good adaptability to harsh environments, they insisted that *R. typhina* remains a good pioneer species in bare hills (Zhang et al. 2005; Chen et al. 2006; Sun 2008; Du 2010).

From another side, some researchers were worried of the utilization of *R. typhina* in afforestation, chiefly for its aggressive growth strategy and high-growth plasticity, high reproduction/spreading rate, and the suppression to other species (Zhang et al. 2004, 2009; Wang et al. 2008; Zhan et al. 2011). As a clonal plant, its ramets had a growth strategy with lateral branch and leaf growing much faster than tree height, which benefits its competition for sunlight resource. Prior transport of photosynthetic products to the lateral roots also favored its spreading (Zhang et al. 2005). Though *R. typhina* has once been classed as shade intolerant, its high plasticity at using available light energy was newly proved (Zhang et al. 2009). Its seedlings could maintain high net photosynthetic and growth rate under full sunlight or moderately low light conditions (50% and 25% full sunlight), meanwhile have the ability to survive severely low light intensity environment (10% and 5% full sunlight), with biomass distribution pattern being unaffected by light levels (Zhang et al. 2009). Studies conducted in the Taihang Mountains also demonstrated its higher water use efficiency against some main native shrubs, such as *Ziziphus jujuba* var. *spinosa* and *Vitex negundo* var. *heterophylla* (Li et al. 2011a, 2011b). Therefore, the opponents considered that the physiological characters of *R. typhina* would make it have a potential advantage in competing for light, soil, and water with native species (Zhang et al. 2004, 2009). From the field investigation aspect for verification, they also documented some evidence. For instance, *R. typhina* individuals increased by 4.5- and 8.1-fold in 3 years in sterile and fertile environments of

Beijing's mountainous area, respectively, with spreading distances both being more than 6 m within the same time span (Wang et al. 2008); meanwhile significantly lower species richness, individual density, and diversity were noted in the *R. typhina* community than those of nearby native *V. negundo* var. *heterophylla* community (Wang et al. 2008). Similar community characters were found in the Taihang Mountains as well (Zhang 2005). As for its competition ability, it was found that *R. typhina* had competed *Cotinus coggygria* out in the mixed forest in 20 years in Shandong province (Li et al. 2004), while another species, *Platycladus orientalis*, which was often used to build mixed forest with *R. typhina*, was heavily suppressed (Zhan et al. 2011). Based on the above-mentioned cases, these researchers urged caution of its utilization in afforestation or further classified *R. typhina* as invasive species in China.

Evidence to support or query the utilization of *R. typhina* was persistently released by both sides; it seemed that consensus on the issue that *R. typhina* is invasive or not in China would not be reached in a short time. One reason was that different stakeholders had varied priorities when comparing the positive and negative impacts of this plant. The advocators were mainly from the forestry industry and they addressed more advantages of *R. typhina* in covering the bare land. When assessing the impacts to ecosystem, they just considered the influence to arbor community meantime neglecting, intentionally or not, the impacts on shrubs. On the contrary, those opponents were almost scientists majored in botany or ecology. They urged caution from the invasiveness and its impacts on biodiversity. Therefore, these different kinds of data assessed were the main reason for the dispute. Another reason, perhaps more important if only from the scientific aspect, is the relative short time span since *R. typhina* was introduced into China. Given the lag phases that may exceed 100 years between introduction and commencement of invasion (Kowarik 2003), the 40 years' time span (since the wide dispersion of this species in China from 1974) may be insufficient to judge the invasion status of *R. typhina*. While the advocators assessed *R. typhina* as not invasive mainly based on *current status* of some areas, opponents were worried of its utilization for its *potential impact* deduced from its physiological characters and some negative impacts observed. This dispute reflected the conflicting philosophies of *preventing potential negative impacts* and *utilizing current advantages* to assess and manage this species.

## Relevant social factors influencing utilization and assessment

The perception and management of an alien species could change over time with increasing deep research (Starfinger et al. 2003). However, in the case of *R. typhina*, social factors played an important role as well in its extension and evocation of the dispute which influenced the WRA significantly.

Since 1978, as China reoriented its national ideology from political struggle to economic development, alleviating environmental degradation has become more important on the central policy agenda (Guo 2002). A series of ecological rehabilitation projects were conducted covering more than half of the total terrestrial area of China (Zhang et al. 2002), including the Three-North Shelterbelt Program (started in 1978), the Taihang Mountain Afforestation Program (1987), the Coastal Shelterbelt Development Program (1991), the National Program to Combat Desertification (1991), and the Sloping Land Conversion Program (1999). These large-scale programs were designed with a common goal of safeguarding lands/resources and producing ecological benefits through watershed protection, erosion control, and afforestation (Xu et al. 2006). Though the implementation of these programs was coordinated at the state level, concrete executions were eventually conducted by local governments with the state power in China becoming increasing decentralized (Jiang 2006; Yeh 2009). For many local governmental officials, the successful performance of these ecological rehabilitation programs was equivalent to increased vegetation cover or making the bare areas look green and productive (Jiang 2006). Therefore, those programs were biased toward planting trees in their early phase (Xu et al. 2004). The survival rate and growth vigor had been the priority for selecting afforestation species. Therefore, it is easy to understand why *R. typhina* was perceived as so desirable and recommended so enthusiastically. In a sense, it was the rehabilitation projects that made *R. typhina* extended so widely. This coincidence could be noted when comparing the time and the area that *R. typhina* was wide dispersed with those of the ecological rehabilitation projects.

Another special social background concerning the WRA on *R. typhina* was the Beijing Olympic construction. Though public attention to biological invasion was persistently increased with the boom of invasion biology in China (Wan et al. 2009), the query on *R. typhina* was not explicitly expressed until it was chosen as one of the main afforestation species in Beijing Olympic construction. The media article published in the newspaper undoubtedly had more influence on public attention than the research paper and soon got high attention from senior officials. As a consequence, the clarification of the question was demanded officially, which made the issue not only a scientific controversy but also with some political sense. This top-down attention further stimulated more interests in the problem. In a sense, compared with the increasing knowledge of the biological characters of *R. typhina*, the specific social background and the right medium that the point was proposed played a more significant role at evoking this dispute.

Additional possible reason, though never expressed directly, was the involving vested interests. *Rhus typhina* has become a popular species in nursery gardens for its wide utilization in afforestation and the high profit with little cost. Searching the Chinese name of *R. typhina* using the Google search engineer, information of the seedling supply holds most of the matching results. Given the huge stock of the seedlings, the final conclusion of the controversy is linked tightly with the grower's economic interests. In addition, for its vigorous growth in harsh environment, *Rhus typhina* has a comparable advantage in afforestation for fast effect, which may make the executer, especially the forestry officials, ignore the possible long-term effect. Therefore, the profitable evidence for the use based on "current status" was persistently released, which lead the assessment to a more complicated situation.

## Considerations about human dimension in WRA

The advocator and opponents of *R. typhina*, no matter their backgrounds, have mainly focused on its biological characters when conducting the weed assessment. However, the current utilization status, i.e., the human dimension in its spreading and extension, needs to be comprehensively considered. Invasions frequently result from interplay of biological and anthropogenic mechanisms, and sometime the human agency may play a decisive role in this process (Kowarik 2003; Li et al. 2011a, 2011b). Secondary releases over long periods may mimic demographic and dispersal processes which lead to a range of expansions, as well as help those species whose propagules are not naturally moved long distances to overcome spatial isolation (Kowarik 2003). From this aspect to consider, kudzu [*Pueraria montana* (Lour.) Merr.] is a good reference when assessing the weed risk of *R. typhina*. As a clonal vine introduced from East Asia, kudzu had been widely planted for various purposes in the first half of the 1900s in the USA (Forseth & Innis 2004). This repeated introduction helped kudzu overcome spatial isolation and facilitated its range expansion. Though millions of dollars were contributed to its control since its noxiousness was recognized in 1950s (Simberloff 2011), this species has covered more than 3 million ha and is still spreading at a rate of 50,000 ha per year (Forseth & Innis 2004). For its invasive status in the USA and elsewhere, kudzu has been listed as one of the 100 world's worst alien species (Lowe et al. 2004). *Rhus typhina* has experienced a similar course of extension in China as kudzu in the USA. Though mainly reproducing with vegetative manner, *Rhus typhina* has currently been widely dispersed with anthropogenic assistance, especially in the mountainous areas (Figure 1). Considering its aggressive growth strategy and the detected negative impacts (Li et al. 2004; Wang et al. 2008), we could not prelude the possible severe problems if *R. typhina* is still widely planted. Therefore, we should not only focus on the biological characters but also need to think about the human dimensions when assessing the weed risk of this having long utilization tradition species.

Certainly human harvest may prevent some species causing major problems, as the examples of kudzu in its native rang, East, and Southeast Asia (Li et al. 2011a, 2011b). However, it is very different when considering *R. typhina*. Even in its native area, *Rhus typhina* has been listed as weed for its aggressive spread and the suppression to some shade intolerant species (Uva et al. 1997). No massive harvest with economic purpose has happened in both its native range and introduced areas. Missing this possible control factor of invasion which acted in kudzu in its native range (Li et al. 2011a, 2011b), *Rhus typhina* could spread extensively with its aggressive growth strategy in natural or semi-natural areas. Actually, the control of *R. typhina* is rather complicated though the advocators thought it is just moderately difficult. It is nearly impossible to eradicate *R. typhina* once the plant is established, unless all of the roots are dug out and taken away, because each root fragment can develop into a new individual. Cutting and fire injury also encouraged its sprouting (Wu et al. 2007; Du 2010). Though chemical control with 41% amiton may be effective when conducted in a plot experiment (Wu et al. 2007), the side effect to other species or the ecosystem is unclear if applied in a large scale. Considering this facet, ceasing its utilization in afforestation and finding an alternative native species may be a better choice.

## The newly released weed assessment system in China: Is it appropriate in practice?

Due to the severe and fast-growing threats of invasive species, numerous studies have been performed attempting to assess the invasiveness of alien species or predict the invasion success with both theoretical and empirical methods (Arim et al. 2006; Bacchetta et al. 2010; Comin et al. 2011). Considerable WRA systems were therefore constructed in many countries based on invasion theory (e.g. Reichard & Hamilton 1997; Pheloung et al. 1999; Weber & Gut 2004; Randall et al. 2008; Koop et al. 2012). Though the false positives or negatives of the WRA system had been queried (Smith et al. 1999), the problem could be ameliorated with improving design, therefore, high-quality WRA systems could still play an important role when dealing with introduction and release of alien species (Koop et al. 2012).

Though China has suffered heavily from biological invasion, researches on WRA systems or protocol were seldom reported except the WRA system for woody plant constructed by Zhang and Zheng (2008). According to this system, the invasiveness, actual spread extent, and ecological impact of an exotic woody species were firstly classified into three ranks (high, moderate, and low) based on a series of multiple choice questions with corresponding scores. As for the three aspects for assessment, invasiveness is evaluated by reproduction, dispersal, and adaptation ability; actual dispersal extent is assessed by natural reproduction, invaded plant community types, and dispersal rate; ecological impact is identified by the influence on environmental factors, structure and function of plant community, local genetic integrality, and nutrition chain in the ecosystem. The invasion risk is then ranked to three levels as well as based on the comprehensive performance of the above-mentioned three aspects. The second stage is the assessment of the control difficulty with a questionnaire consisting of many indicators. In the end, three introduction strategies (prohibited, limited, and free) are recommended according to the consideration of both invasion risk class and control difficulty class. This WRA system had been adopted and released by the State Forestry Administration of China as forestry industry standard for invasion risk assessment of alien tree species to the natural ecosystem (State Forestry Administration of China 2011).

However, this WRA system needs to be discussed from the viewpoint of invasion biology. First, when a WRA system was designed and validated, accuracy test by a set of well-known invasive and non-invasive species is indispensable (Reichard & Hamilton 1997; Pheloung et al. 1999; Weber & Gut 2004; Randall et al. 2008; Koop et al. 2012). However, this WRA system only used three species as training data for its justification, including common lantana (*Lantana camara* L.), yellow locust (*Robinia pseudoacacia* L.), and *R. typhina*. This insufficient examination could test neither the true positive/negative nor false positive/negative, therefore, could not justify its credibility from a statistical view. Furthermore, the selection of *R. typhina*, which is still very contentious at its invasive risk in China, as noninvasive species according to their own viewpoint (Zhang et al. 2005) to justify the WRA system they developed, is improper. Second, for the alien species which had passed a life cycle at the introduced area, the WRA system just evaluated its actual dispersal extent irrespective of the invasiveness. This reflected a "current status-based" design principle, neglecting the lag phases in biological invasion. In addition, the indicators the system adopted as well as the corresponding scores need reconsidering. Many well-performed WRA systems (e.g. Reichard & Hamilton 1997; Koop et al. 2012) used mathematical models to select the predicting indictors or evaluated against the opinions of several groups of expert during the development course. However, this process did not represent in the primary paper (Zhang & Zheng 2008), and no subsequent test or interpretation was reported before adopted by State Forestry Administration of China. Absence of the indispensable procedure made this WRA system some arbitrariness in indicator selection, scoring, and the classifiying of invasive risk. For example, "invasive elsewhere" has been proved as one of the most effective predictors for invasion risk of woody species (Pheloung et al. 1999; Herron et al. 2007; Koop et al. 2012). Regretfully, this important indicator was not considered in the assessment system. Therefore, the propriety of this WRA system with many flaws in practice is questionable. We worry the WRA system may play a negative role as this system could let some potential invasive plant species pass the assessment and be introduced freely in the name of this guideline. The forestry industrial standard for invasion risk assessment of exotic tree species should not be built only by researchers within the forestry department. Its validation needs more rigorous assessment and close cooperation with experts from other institutions (Celesti-Grapow et al. 2009, 2010; Xu & Qiang 2011), especially when the drafter's opinion for a given exotic species was so sharply contrary to many researchers.

## Discussion

Many contentious invasive species are usually economically or commercially valuable while having some weedy attributes, which impact the perceptions of different stakeholders and cause disagreement in management (Kull et al. 2011; Marshall et al. 2011). When concerning those species that are mainly utilized for ecological restoration with little direct economic values, the ecological impacts should be the focus when conducting evaluation. It seems that the dispute on such species may be only a pure scientific issue just under ecological context. However, as the case of *R. typhina* as we demonstrated here, it is also influenced by many other factors such as the introduction history, current utilization status, and divergent underlying values varying through persons and sectors. These factors will determine the kind of data to be assessed, which lead to different evaluations. Therefore, the disagreement on a specific alien species should be comprehensively analyzed with scientific and social factors considered simultaneously. Invasive species are defined as the subset of alien species that cross a threshold for disproportionate negative impact to the ecosystem, and this definition in no way precludes an "invasive species" having some positive impacts (Russell 2012). The assessment should be conducted under a proper ecological context and based on a fully story, otherwise it may cause risk of sending distorted or mixed messages to managers (Rodewald 2012). To prevent or reduce the damages to ecosystems due to biological invasion, the WRA not only needs comprehensive knowledge of given alien species but also should preclude the influence of some invested interests.

As for the WRA system newly released in China, it needs much improvement. For the purpose of scientific research, a WRA protocol could be proposed for discussion even if it is relatively immature. However, if officially released as a national standard, it must pass sufficient and more rigorous examination to justify its priority in practice, otherwise, it may play an opposite role. We therefore strongly suggest that the adoption of this questionable WRA system be reconsidered carefully. Considering the huge damage caused by invasive species and the cost to deal with the problem, stricter WRA should be adapted as mistakes can take many decades to become obvious and are often irreversible (Iberite et al. 2011; Low 2012). A conservative policy, such as "guilty until proven innocent", may be more effective in China and elsewhere (Reichard & Hamilton 1997; Mack et al. 2000; Simberloff 2003). The "black list" method and "green list" approach with rigorous expert assessment should be adopted simultaneously in the introduction and management of exotic species (Simberloff 2006; Schmutz 2011). Furthermore, some important developments in vegetation patterns research (e.g. Feoli 2012; Peterson & Soberon 2012) should be considered and applied in practice when assessing the spatio-temporal impacts of a given alien species to the ecosystem, which may help offer more objective and accurate data for evaluation. The construction of a national vegetation database and primary biodiversity data, which had raised high attention and made much progress in European countries and worldwide (Martellos et al. 2011; Basset & Los 2012; Holetschek et al. 2012; Landucci et al. 2012), should also be strengthened for public education and participation in invasive species management.

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