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A Method for Quantifying the Relative Level of Potential Invasiveness of Invasive Alien Plants

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Abstract

Quantitative assessment of invasiveness serves as a fundamental prerequisite for elucidating the driving mechanisms behind successful invasions of invasive alien plants (IAPs). However, a standardized, comprehensive, and operationally feasible methodology for quantifying the relative potential invasiveness of IAPs remains underdeveloped. This study aims to establish a comprehensive methodology that enables convenient, operational, and feasible quantification of the relative potential invasiveness of IAPs. The proposed framework integrates a multidimensional indicator system spanning the entire life history of IAPs—including germination, growth, reproduction, dissemination, and litter decomposition—while also incorporating critical but often unquantifiable or difficult-to-quantify traits that may drive invasion success. The results are expected to provide a robust scientific basis for determining IAP invasiveness levels and assessing ecological risks, thereby laying a theoretical foundation for early warning, prevention, control, and management against IAP invasions.

Keywords: Ecological Risk; Natural Enemies; Stress; Successful Invasion; Tolerance

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Biological invasions mediated by invasive alien species, including invasive alien plants (IAPs), constitute both a critical component and a key driver of global change [4, 6, 16, 17]. These interacting processes—global change and biological invasion—are profoundly altering the species composition, structure, and functioning of ecosystems worldwide. Such alterations pose severe threats to biodiversity security and have emerged as a major environmental challenge on a global scale [1, 2, 9, 20]. In particular, IAPs can suppress the growth of native plants through strong competitive ability, leading to the decline or exclusion of native species with relatively weaker competitive ability, thereby reducing native plant diversity [4, 8, 12, 20]. Additionally, IAPs can also alter soil physicochemical properties, soil nutrient cycling, soil enzyme activity, as well as the community structure and metabolic activity of soil microorganisms [9, 16, 21, 25]. A more critical issue is that the impacts of invasive alien species span a wide range of ecosystems, including croplands, wetlands, grasslands, forests, and rivers and lakes, etc. Consequently, elucidating the key mechanisms that drive the successful invasion of invasive alien species, particularly IAPs, has become a research priority [9, 13, 14, 24].

Quantitative assessment of invasiveness is a critical prerequisite for elucidating the driving mechanisms behind the successful invasion of IAPs. To this end, previous studies have developed various metrics to characterize the invasiveness of IAPs, including: the invasion degree index [10], the invasion intensity index [23], the relative invasiveness index [23] and the competitive advantage index [22]. These metrics provide valuable tools for quantifying specific aspects of plant invasiveness.

The successful invasion of IAPs is likely mediated by a combination of multiple biological and ecological processes, spanning their entire life history from germination, growth, and reproduction to dissemination and litter decomposition [5, 11, 18]. It is noteworthy that certain traits closely associated with plant invasiveness are readily quantifiable, including population parameters (e.g., individual count, relative abundance, and relative coverage), morphological traits (e.g., plant height, leaf size, and specific leaf area), as well as physiological and ecological attributes (e.g., photosynthetic capacity and biomass). In contrast, a considerable number of characteristics—such as taxonomic identity, life form, growth cycle, leaf morphology and texture, ecotype, reproductive strategy, pollination mechanism, and seed dispersal mode—are inherently difficult or impossible to quantify using conventional numerical metrics. Despite their non-quantitative nature, these intrinsic biological attributes may play a crucial, and often overlooked, driving role in the invasion process. They can significantly influence the invasiveness of IAPs, yet existing methods for quantifying invasion risk predominantly focus on measurable parameters, largely neglecting these functionally important but hard-to-quantify traits. Moreover, while the majority of studies have analyzed and elucidated the impacts of quantifiable traits on invasiveness and the underlying invasion mechanisms [3, 7, 15, 19], the role of non-quantifiable characteristics in shaping competitive outcomes is frequently ignored. Critically, there remains a lack of a standardized, comprehensive, and operationally feasible methodology for quantifying the relative potential invasiveness of IAPs in a holistic manner. Therefore, it is imperative to establish a set of simple, scientifically sound, and practical criteria that can effectively incorporate the contributions of both quantifiable and non-quantifiable characteristics to assess the invasiveness of IAPs accurately.

This study proposes a comprehensive framework for the quantification of the relative potential invasiveness of IAPs, designed to be both scientifically robust and practically feasible.

A key innovation of this study lies in the construction of a multi-faceted indicator system that moves beyond traditionally quantifiable metrics. By incorporating a wide spectrum of often-overlooked non-quantifiable traits—such as species category, life form, reproductive mode, and ecological adaptability—alongside standard life-history parameters, the proposed framework offers a more nuanced and comprehensive approach to assessing the relative invasiveness of invasive alien plants.

The criteria for quantitatively evaluating the relative potential invasiveness of IAPs are detailed in Table 1.

This study outlines a comprehensive, practical, and operationally feasible methodology for quantifying the invasiveness level of IAPs. The results thus provide a robust scientific basis for determining IAPs' invasiveness levels and assessing their ecological risks, especially in croplands, wetlands, grasslands, forests, and rivers and lakes. Furthermore, the findings establish a substantial theoretical foundation for the early warning, prevention, control, and management of IAPs' invasions.

Given that IAPs exhibit significant variations in species identity, invasion stage, history, and mechanisms across different regions and ecosystems, a fixed assessment indicator system may lack universal applicability. Therefore, future assessments of potential invasiveness should be comprehensive and tailored to local contexts.

Competing Interests

The authors declare that they have no conflict of interest.

Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

Table 1: A set of simple, scientific and feasible criteria for quantifying the relative level of the potential invasiveness of invasive alien plants. In particular, invasive alien plants with higher scores possess stronger potential invasiveness compared to those with lower scores. In addition, the potential invasiveness of invasive alien plants can be categorized into the following three levels, namely: (1) less than 50 (can be classified as general invasive alien plants, which may pose a relatively low ecological risk); (2) between 50 and 100 (can be classified as severe invasive alien plants, which may pose a serious ecological risk); and (3) greater than 100 (can be classified as malignant invasive alien plants, which may have an extremely high ecological risk).

Characteristics of invasive alien plants	Category	Score assigned
Species category	Angiosperm	3
	Gymnosperm	2
	Other types of plants	1
Life form	Trees	4
	Shrubs	3
	Woody vines	2
	Herbaceous vines	2
	Herbs	2
	Succulent plants	1
Growth cycle	Perennial plants	3
	Biennial plants	2
	Annual plants	1
Leaf type	Broadleaf	2
	Needle	1
Leaf texture	Herbaceous leaf blade	4
	Leathery leaf blade	3
	Membranous leaf blade	2
	Paper leaf blade	1
	Succulent leaf blade	1
The growth status of leaves	Evergreen plants	2
	Deciduous plants	1
Ecotype	Amphibious plants	2
	Terrestrial plants	1
	Aquatic plants	1
Plant height	Extremely high	4
	Relatively high	3
	Relatively short	2
	Extremely short	1
Reproduction mode	Asexually and sexually reproduced plants	2
	Asexually reproduced plants	1
	Sexually reproduced plants	1
Length of flowering period	Extremely long flowering period	4
	Relatively long flowering period	3
	Relatively short flowering period	2
	Extremely short flowering period	1
Size of single flower	Extremely big flowers	4
	Relatively big flowers	3
	Relatively small flowers	2
	Extremely small flowers	1
Pollination mode of flowers	Self-pollinated flowers	4
	Wind-pollinated flowers	3
	Insect-pollinated flowers	2
	Other pollination methods	1
Flower type	Inflorescences	3
	Single flower with stamens and pistils	2
	Single flowers with stamens or with pistils	1

Seed size	Extremely small seeds	4
	Relatively small seeds	3
	Relatively big seeds	2
	Extremely big seeds	1
Seed number	Extremely numerous	4
	Relatively numerous	3
	Relatively few	2
	Extremely few	1
Seed structure	With structures such as crown hairs or barbs	2
	No structures such as crown hairs or barbs	1
Seed dissemination mode	Relying on the power of the wind	3
	Relying on the power of animals	2
	Relying on one's own strength	1
Seed dormancy	Seeds have obvious dormancy and only germinate under certain environmental conditions	2
	Seeds do not have obvious dormancy	1
Decomposition rate of litters	Extremely fast	4
	Relatively fast	3
	Relatively slow	2
	Extremely slow	1
Shade tolerance	Extremely strong	4
	Relatively strong	3
	Relatively poor	2
	Extremely poor	1
Drought tolerance	Extremely strong	4
	Relatively strong	3
	Relatively poor	2
	Extremely poor	1
Flood tolerance	Extremely strong	4
	Relatively strong	3
	Relatively poor	2
	Extremely poor	1
Heat tolerance	Extremely strong	4
	Relatively strong	3
	Relatively poor	2
	Extremely poor	1
Cold tolerance	Extremely strong	4
	Relatively strong	3
	Relatively poor	2
	Extremely poor	1
Barrenness tolerance	Extremely strong	4
	Relatively strong	3
	Relatively poor	2
	Extremely poor	1
Environmental pollution tolerance	Extremely strong	4
	Relatively strong	3
	Relatively poor	2
	Extremely poor	1
High osmotic tolerance	Extremely strong	4
	Relatively strong	3
	Relatively poor	2
	Extremely poor	1
The responsiveness to climate change factors such as rising carbon dioxide levels	Extremely strong	4
	Relatively strong	3
	Relatively poor	2
	Extremely poor	1
Tolerance to external disturbances	Extremely strong	4
	Relatively strong	3
	Relatively poor	2
	Extremely poor	1
Allelopathic intensity on other adjacent plants (especially the native plants)	Extremely pronounced allelopathy	4
	Relatively pronounced allelopathy	3
	Less pronounced allelopathy	2
	No pronounced allelopathy	1
Toxicity of plants	Extremely strong	4
	Relatively strong	3
	Relatively poor	2
	Extremely poor	1
Symbiotic relationships with beneficial microorganisms (such as nitrogen-fixing bacteria and arbuscular mycorrhizal fungi)	The symbiotic relationship formed is strong	4
	The symbiotic relationships formed are relatively strong	3
	The symbiotic relationship formed is not strong	2
	Failure to form a symbiotic relationship	1
Number of natural enemies	Extremely few	4
	Relatively few	3
	Relatively numerous	2
	Extremely numerous	1
Presence of natural enemies	Basically no natural enemies	4
	Presence of broad spectrum of natural enemies	3
	Presence of specialized natural enemies	2
	Presence of broad spectrum of natural enemies and specialized natural enemies	1
The area of community formation in the wild	Extremely large	4
	Relatively large	3
	Relatively small	2
	Extremely small	1
The effects on native plant diversity	Extremely inhibition	4
	Relatively inhibition	3
	Relatively promotion	2
	Extremely promotion	1
Whether special ecological conditions are required	No	2
	Yes	1
Adaptability to diverse habitats	Extremely strong	4
	Relatively strong	3
	Relatively poor	2
	Extremely poor	1
Can large-scale monodominant communities form at the same region in the wild	Yes	2
	No	1
Distribution range	Widely dispersed (numerous regions)	4
	Relatively wide (multiple regions)	3
	Relatively small (fewer regions)	2
	Extremely small (smaller regions)	1

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