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Review Article

ASSUMPTIONS FOR SUCCESSFUL PLANT INVASION AND PAKISTAN'S STANCE REGARDING BIOLOGICAL POLLUTION

Huma Qureshi[1*], Muhammad Arshad[1]

[1]Department of Botany, PMAS-Arid Agriculture University, Rawalpindi, Pakistan

Abstract. Invasive species have abundances in new ranges than in native environments. Understanding the mechanisms of plant invasions is challenging but crucial to invasive species management and future invaders prediction. The past several years have witnessed numerous new researches to determine plant invasion mechanisms. Here we summarize some of important hypothesis presented to explain invasion success. Moreover, this paper provides comprehensive inventory of invasive plants in Pakistan. Invaders with high impact in terrestrial ecosystems are also discussed.

Keywords: *Biological pollution, invasion mechanisms, Novel weapons hypothesis (NWH), plant invasions.*

Corresponding Author: *Huma Qureshi, Ph.D., Department of Botany, PMAS-Arid Agriculture University, Rawalpindi, Pakistan, e-mail: humaqureshi8@gmail.com*

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1. Introduction

The biological pollution (invasion of ecosystems by alien species) is the second key driver of biodiversity loss and global environmental change after habitat destruction [34,37]. The invasions by foreign species are likewise recognized to affect ecosystem services [9] and human well-being [33,36]. Invading alien plants, because of their ability to alter ecological processes such as hydrological cycles [5], carbon and nitrogen cycling [13,29], frequency and/or intensity of fire [4] and normal disturbance regimes in the native communities [12,47], have transformed many ecosystems by out-competing native species [27] and hence, are rightly regarded as one of the most significant threats to biodiversity on Earth [8,11,47].

Biological invasion represents one of the most important factors of global environmental change [44,46]. Though transport of plant species has occurred in the past, current movements are fast and involve more distant areas, principally as a consequence of increased global commerce and travel [20,28,30,38,44]. During exotic invasions, human activities help invasive species overcome oceanic barriers via sweepstakes route and also facilitate establishment, naturalization and rapid dispersal [40]. Therefore in invasion ecology, human mediated introductions of exotic organisms, especially in regions well outside their potential range, as determined by their natural dispersal mechanisms and bio-geographic barriers are observed.

Invasive alien plants need to go through five stages of barriers to invade a new area, coded as 5Es - Entry/Escape, Establish, Expand, Explode and Entrench [49]. These phases are often influenced by abiotic factors like climate. Biological invasions affect virtually all ecosystems on the Earth, but, the extent of invasion of different areas and biomes and the quality of data emanating from them varies greatly [15,31].

Understanding the mechanisms of plant invasions has been a challenging task for ecologists for decades, but is crucial to invasive species management and future invaders prediction. The past several years have seen numerous new studies to determine plant invasion mechanisms. Updated analysis of the comparative importance of different invasion mechanisms would be helpful for either a general comprehension of the occurrence of plant invasions or predicting future invaders.

2. Key hypothesis for invasion success

2.1. Williamson's (1996) 'tens' rule of thumb of biological invasions: Most introduced plants do not become invasive. Only 10% of introduced species will become established in a host environment and that only 10% of the established invaders will become pests. The extent to which an introduced plant naturalizes and spreads depends on the suitability of the new physical, chemical and biological environment in which it sees itself. If these factors are unsuitable, the plant is unlikely to become grounded [50].

2.2. The intermediate disturbance hypothesis (IDH): Diversity of competing species is maximized at intermediate frequencies and/or intensities of disturbance or environmental change [39].

2.3. Enemy release hypothesis (ERH)/ herbivore escape, predator escape or ecological release hypothesis: Diversity of competing species is maximized at intermediate frequencies and/or intensities of disturbance or environmental change [39].

2.4. Propagule Pressure (PP): High supply and frequency of plant propagule introductions increase chance of successful invasion due to high genetic diversity, seed swapping, continual supplementation, higher probability of introduction to favorable environment [10].

2.5. Invasional meltdown (IM): Direct or indirect symbiotic or facilitative relationships among invaders cause an 'invasion domino effect'. Often takes place over a range of trophic levels, where one species makes habitat or community more amenable for the other [30].

2.6. Evolution of Increased Competetive Ability (EICA): Selection favors genotypes which have allocated resources, which are no longer needed for defense to adapting and enhancing the competitive ability [2,7].

2.7. Ideal Weed (IW): Invasive species share traits that facilitate invasions enabling them to outcompete indigenous species [43].

2.8. Disturbance (DS): Disturbance events open window of opportunity for invasive species [19].

2.9. Limiting similarity (LS): Successful invaders are functionally distinct from species in the recipient community, so encounter minimal competition and can fill an empty niche. Limiting similarity causes trait/phylogenetic over-dispersion [18].
2.10. Enemy Reduction (ER): Rather than complete release, reduction in the number of enemies [10].
2.11. Enemy of my enemy (EE): Enemies have a stronger effect on indigenous species resulting in apparent competition. Invader accumulates generalist pathogens, which greatly infect native species and reduce their ability to outcomplete invading plants [14].
2.12. Habitat filtering (HF): Invader successful as it is adapted to conditions of ecosystem and able to pass through the environmental filters. HF leads to trait under dispersion and phylogenetic clustering [35].
2.13. New associations (NAS): Invading species form new relationships with species in the invaded community, which enhance or impede invasion success [10].
2.14. Biotic indirect effects (BID): Includes a range of mechanisms that can facilitate invasion as a result of indirect community interactions, i.e. how 'a' alters the effect that 'b' has on 'c' [48].
2.15. Novel weapons Hypothesis (NWH): Invading species release allelopathic compounds that inhibit and repress potential competitors in new range. Endemic species are not accommodated to the novel chemical weapons, enhancing the invader's competitive ability and success [7].
2.16. Environmental heterogeneity (EVH): Habitats with high environmental variability contain a diverse array of niches that can host a variety of species. The encroachment will be successful if there are an insufficient number of indigenous species to occupy the available niches (i.e. indigenous species pool too small) [35].
2.17. Increased resource availability (IRA): Species require resources for settlement and establishment so an increase in resource levels provides an opportunity for invasion [10].
2.18. Dynamic equilibrium model (DE): Disturbance and productivity interact to affect invasion, and each factor can reverse responses driven by the other. Invaders can readily establish in low disturbance–low productivity systems (but not very unproductive ones), but only become dominant in high productivity systems with high degrees of disturbance (required to build) [23].
2.19. Empty niche (EN): Due to a limited indigenous species pool, the recipient, community and ecosystem are unsaturated so invaders can use the spare resources and absorb the unused niches (i.e. there is room for the invaders) [18].
2.20. Resource–enemy release (R-ER): Combines ER and IRA, but notes that invasion can be sped up and enhanced when both occur [3].
2.21. Missed mutualisms (MM): Upon entering into a new range invading species will lose the beneficial mutualistic relationships that they experience in home range, thereby impeding invasion [1].

3. Status of plant invasion in Pakistan

Pakistan has a long history of introduction of exotic plant and creature species. Most of current alien invasive in Pakistan were deliberately introduced with the main objective behind to meet the gap between demand and supply of quality, fuel wood and fodder [22]. Fortunately the magnitude of IAS in Pakistan is not as large as in some other states. The meager studies undertaken so far list 700 alien species of vascular plants [26]. Of reported aliens, 73 species are regarded with status of invaders in the country (Table 1); which include *Broussonetia papyrifera*, *Prosopis juliflora*, *Parthenium hysterophorus* and *Lantana camera* that are noted as high-impact land invaders threatening the native biodiversity (Table 2) [21].

Table 1. Contribution of different life forms in Invasive flora of Pakistan[1]

Taxonomic name	Common name	Family
***INVASIVE FERNS**		
Salvinia molesta Mitch.	Water fern	Salviniaceae
***INVASIVE GRASSES**		
Arundo donax L.	Nar, Nara, Nal.	Poaceea
Avena fatua L.	Jangli Jai	Poaceae
Bromus unioloides Kunth	Prairie grass, rescue grass	Poaceea
Cynodon dactylon (L.) Pers.	Dub, Khabbal	Poaceea
Dactylis glomerata L.	Orchard grass	Poaceea
Imperata cylindrica (L.) Raeuschel.	Sword grass, Blady grass, Siru, Ulu	Poaceae
Lolium temulentum L.	rye grass, Dhanak	Poaceae
Phalaris minor Retz.	Dumbi sitti	Poaceae
Phragmites australis (Cay.) Trin. ex Steud.	Ditch Reed, Nal, Dila	Poaceae
Phragmitis karka (Retz.) Trin. ex Steud	Drumbi, Nar, Nalu	Poaceae
Sorghum halepense (L.) Pers.	Baru, Baran	Poaceae
Vulpia myuros (L.) C.C.Gmel.	Rat-tail fescue	Poaceae
***INVASIVE HERBS**		
Agave americana L.	Agave	Agavaceae
Alternanthera pungens Kunth	Khaki booti	Amaranthaceae
Amaranthus hybridus L. subsp. hybridus	Chalwera	Amaranthaceae
Achillea millefolium L.	Yarrow	Asteraceae
Amaranthus spinosus L.	Spiny Amaranth	Amaranthaceae
Amaranthus viridis L.	Chulai	Amaranthaceae
Asphodelus tenuifolius Cavan. L.	Piazi, Pimaluk	Liliaceae
Cannabis sativa L.	Hemp, Mirijuana, Bhang	Cannabaceae

[1] Inventory proposed based on literature available in invasion biology [16,17,21,24,25,32,37,41,42,45].

Taxonomic name	**Common name**	**Family**
Carthamus oxyacantha M. Bieb.	Pohli	Asteraceae
*Cassia occidentalis*L.	Kasondi	Caesalpinaceae
Conyza bonariensis (L.) Cronq.	Horseweed	Astraceea
Datura stramonium L.	Thorn apple, Dhatura	Solanaceea
Echium plantagineum L.	Purple Vipers Bugloss, Blue Weed	Boraginaceea
Eichhornia crassipes (Mart.) Solms.	water hyacinth, gul-e-bakauli	Pontederiaceae
Emex spinosus (L.) Campd.	Prickly dock; Kafir kanda	Polygonaceea
Galium aparine L.	Catchweed, bedstraw	Rubiaceae
Heracleum polyadenum Rech. f. & Riedl.	---	Apiaceae
Ipomoea eriocarpa R. Br.	Ilra, Bhanwar	Convolvulaceae
Leucanthemum vulgare Lam.	Ox-eye daisy	Asteraceae
Lotus corniculatus L.	---	Papilionaceae
Malva parviflora L.	Sonchal	Malvaceea
Medicago lupulina L.	Black medic	Papilionaceae
Medicago sativa L.	Alfalfa, Lusan	Papilionaceae
Parthenium hysterophorus L.	White top, Congress grass, Carrot grass	Asteraceae
Pistia stratiotes L.	Water lettuce; Jal kumbi	Araceae
Plantago lanceolata L.	Danichk, Brohi Barz	Plantaganaceae
Rumex conglomeratus Murray	Clustered dock	Polygonaceae
Rumex crispus L.	Curly dock	Polygonaceae
Sida cordata Blumea	Sida	Malvaceea
Silybum marianum(L.) Gaertn.	Kandiari	Astraceea
Tagetes minuta L.	Gul-e-Sadbarg; Mexican marigold	Asteraceae
Trianthema portulacastrum L.	It-sit, Wisakh	Aizoaceae
Trifolium dubium Sibth.	Suckling clover	Papilionaceae
Trifolium pratense L.	Red clover	Papilionaceae
Verbascum thapsus L.	Jangli Tamak, Sfaid bhang	Scrophulariaceae
Verbena tenuisecta Briq.	Moss verbena	Verbinaceea
Veronica persica Poir.	Common field speedwell	Scrophulariaceae
Xanthium strumarium L.	Common cocklebur	Asteraceae
***INVASIVE SHRUBS**		
Cassia obtusifolia L.	Chakunda	Caesalpinaceae
Duranta repens L.	Golden dewdrop, pigeon berry, skyflower	Verbinaceea
Ipomoea carnea Jacq.	railway creeper	Convolvulaceae
Lantana camara L.	Panch phuli	Verbenaceae
Nerium oleander L.	Kunair, Ganira	Apocyanaceae
Ricinus communis L.	Arind	Euphorbiaceae

Taxonomic name	Common name	Family
***INVASIVE TREES**		
Ailanthus altissima (Mill.) Swingle	Tree of heaven	Simarubaceae
Bougainvillea glabra Chosy	Paper flower	Nyctaginaceae
Broussonetia papyrifera (L.) L'Herit. ex Vent	Paper mulberry, Gul toot	Moraceae
Citharexylum spinosum L.	Ratanuath	Verbinaceea
Eucalyptus camaldulensis Dehnh.	sufeda, lachi	Myrtaceae
Eucalyptus citriodora Hook.	Lemon eucalyptus	Myrtaceae
*Eucalyptus sideroxylon*A. Cunn. ex Woolls	Red Ironbark	Myrtaceae
Eucalyptus tereticornis Smith	Forest red gum	Myrtaceae
Leucaena leucocephala (tant.) De wit.	Ipil ipil, Kubabhal	Mimosaceae
Ligustrum lucidum Ait.	Glossy privet	Oleaceea
Morus alba L.	White mulberry, Sfaid tut	Moraceae
Pistacia chinensis Bunge	Chinese pistacia, green almond	Anacardiaceae
Prosopis juliflora (Sw.) DC.	Kabuli kikar, valayati jand	Mimosaceae
Robinia pseudo-acacia L.	Black locust	Papilionaceae
Sapium sebiferum (L.) Roxb	Pahari Shisham	Euphorbiaceae
Thuja orientalis L.	Mor Pankh	Cupressaceae

Table 2. High impact invaders in terrestrial ecosystems of Pakistan

Invader	Possible reason of invasiveness	Major Impacts
***Broussonetia papyrifera* Vent.**	The rapid growth rate, effective dispersal by birds and strategy of vegetative regeneration	Flower pollens are serious human allergen, indigenous flora replacement
***Prosopis juliflora* (Sw.) DC.**	Exceptional tolerance of drought, high salinity and water logging as well as prolific seed production	Indigenous vegetation habitat elimination, cattle poisoning
***Lantana camara* L.**	Fast growth rate, Seeds dispersal by birds	Change in vegetation picture of certain areas, repel the associated fauna by its strong odor, cattle poisoning
***Parthenium hysterophorus* L.**	Fast growth rate, high reproductive potential, adaptive nature (photo insensitivity and drought resistant), allelopathy and absence of natural enemies	Aggressive competitor with biodiversity and health impacts

4. What Pakistan is doing to manage invasions?

Keeping in view the impact of invasive weeds on environment, article 8(h) of the Convention on Biological Diversity (CBD) signed by 161 countries at the Earth Summit in 1992; urges the parties to "prevent the introduction of, control, or eradicate those alien species which threaten ecosystem, habitat or species" and Pakistan being a member of CBD, is judiciously playing its role.

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