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Invasive Common Reed (*Phragmites australis* (Cav.) Trin. ex Steud.): A Serious Ecological Threat to Ladakh Tethys Himalayan Biodiversity in Changing Climate

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Abstract

Ladakh's cropped and non-cropped areas suffer greatly from weedy invasion under subsistence agricultural system where weeding is not a priority but total crop + weed biomass together contribute to livestock feeding significantly. As agriculture along with livestock rearing is major activity of livelihood options, thereby contributing significantly to Ladakh economy and income generation for supporting resource poor farmers. Amongst various invasive weed species, the common reed *(Phragmites australis)* has become a serious ecological threat for agri-silvi-pastoral system biodiversity and accelerated its expansion in cropped lands including many wetland and salt-affected habitats of cold arid region due to its intermediate plant growth habit of C3 - C4 photosynthetic ecotypes. This character makes *Phragmites* a climate-resilient species, which is a major challenge for cold arid agriculture in the changing climatic patterns. Simultaneously, it is one of the best fodder substitute available under harsh climate. This paper deals with its unique characters and potential threats to the agrobiodiversity of Ladakh.

Keywords

Phragmites, Ecology, Biodiversity, Fodder, Ladakh

1. Introduction

Ladakh, cold arid region is one of the highest plateaus of Indian Himalayan Region (IHR), encompassing a large landmass and lying between 32˚15˚N - 36˚N and 75˚15'E - 80˚15'E. This region remains cut off for almost seven months *i.e.* from October to May due to harsh winters coupled with heavy snowfall. Aridity rather than elevation reduces Ladakh to desolation, a vast 'Dust Bowl' and people have attuned to the harsh environment by using various adaptive measures (Bhattacharyya, 1991). However, the people practice small-scale agriculture adapted to such extreme environment by harvesting the glacier water. At present, Ladakh is undergoing economical and land use changes in terms of irrigation development, farming practices and tourism with large military presence (Fox et al., 1994). On the other hand, water scarcity and lack of adequate green cover are the biggest challenges for this region. Consequently upon adaptation due to climate change, the changing environmental conditions impact plant diversification and elevational gradients provide unique opportunities (Nataraj et al., 2022) for newer plant species for upward shift (Klanderud & Birks 2003) of alien invasive species along an altitudinal gradient (Dar et al., 2018). Under cold arid region, livestock pasture becomes a large landfill and a breeding ground (Singh, 2021) for new species to inherit in this region under changing climate. As a result of this, subsistence agricultural practices overlook the presence of new species which find opportunities to adapt and multiply further on the fragile ecosystem in Ladakh. This zero waste society faces a serious management problem. Under such situation, the species of the genus, *Phragmites* have been observed commonly growing along marshes and riversides including cultivated zones wherever moisture regime exists. There are two species (Bor, 1960; Karthikeyan et al., 1989), viz. *P. karka* (Retz.) Trin. ex Steud. and *P. australis* (Cav.) Trin. ex Steud differs in their physiological characteristics (Kandwal et al., 2010). This amphibious species, *Phragmites australis* is a transitional species and has capability to grow well at extreme environmental conditions (Mal & Narine, 2004; Shrivastava et al., 2014) and has been observed to adapt to various ecosystems from aquatic to terrestrial and upgrading to valleys, particular in crop fields. The main factor with this species is very difficult to manage and eradicate as this has very deep and extensive root system, impacting the crop yield to reduce by more than 60 percent as well as impairing the adjoining ecosystems. At present, its geographical distribution has extended from cold temperate regions to the hot as well as moist tropical wetlands (Lessmann et al., 2001) and worldwide spread (Tucker, 1990) is an endemic to North America with rapid encroachment to other parts (Niering & Warren, 1977; Hauber et al., 1991; Marks et al., 1994; Fell et al., 1998). Thereby its infestation was surveyed in all possible sights to understand the spread with adaptive mechanisms and possible interventions to manage this under barren ecosystems.

2. Materials and Methods

This paper is based on bio-geographical extensive surveys of the ecology, natural

establishment of the targeted and problematic weedy species, *Phragmites australis*, and qualitative/quantitative observations of infested areas for consecutive four years *i.e.* 2015-18 with the major objective to find out the occurrence and reason behind its adaptive nature in non-cropped situations and further to cropped areas along the Indus plains and to record the impact on the biodiversity and productivity of crops in cold arid Ladakh region. For its possible utilization pattern, samples were collected for the fodder value. As this weed was not assessed due to non-availability in deep valleys but adapted along the Indus plains where adequate moisture sustains for its growth and development. Studies were carried out in identified villages situated along the river: namely Spituk, Chushot, Palam, Thiksey, and Stakna by observing its growth and its impact on crop yield under different soil types. For the management of *Phragmites*, trial on herbicide screening and its possible utilization were explored. Soils of these villages are described as skeletal, calcareous with an alkaline reaction with poorly developed (A-C profile) moderately deep, coarse-loamy type Cryorthents (Sehgal, 1973) range from gravely and sandy loams on the alluvial fans to sandy and silt clay loams on the flood plains of Indus. Sediment deposits by the river are restricted to small areas along these villages (Klimes & Dickoré, 2005). Infestation of this weed in Leh valley along the Indus river belt was surveyed and mapped using remote sensing and geographical information system. High resolution satellite Sentinel data having 10 m resolution has been used for land use and land cover mapping and Google-earth data having 1 m resolution is used for reference. The irrigation water quality of Indus valley is 7.93 pH, 265.9 $\mu S \cdot cm^{-1}$ electrical conductivity with 127.3 TDS, 1.18 chlorine$\cdot mel^{-1}$ (Acharya et al., 2012). Due to high altitude and low humidity, the radiation level is very high. The global solar radiation is as high as 6 - 7 Kwh/mm (which is among the highest in the World) and air is very dry and relative humidity range from 6% - 24% (Shah, 2012).

Weed diversity hypothesis (WDH) This hypothesis aimed at exploring the plant species actually imposing degradation in non-cropped areas and competition with crops during critical period was attained during growth of cropping period and grasslands and the intensity/degree of competition posed amongst the plant communities for resources and impact on growth parameters and yield attributes. WDH reveals the novel prediction that how weedy diversity impact crops yields under controlled and non-controlled phases, and will also determine the extent to which weed-crop competition weakens the crops and calculate critical periods.

3. Research Results and Discussion

Ladakh, being the highest plateaus in the world, has a large tract of high mountains along the upper Indus River of the West Himalaya and lies between 32˚15'N - 36˚N and 75˚15'E - 80˚15'E. This region remains cut off for almost seven months *i.e.* from October - May from rest of the world by surface trans-

portation due to harsh winters coupled with heavy snowfall. Aridity rather than elevation reduces Ladakh to desolation, a vast "Dust Bowl" and Ladakhi (people of Ladakh) have adjusted to the harsh environment by using the available natural resources. Botanically, this region is shaped by the joint effect of elevation and isolation amidst snowy mountains (Bhattacharyya, 1991). However, the people practice small-scale agriculture adapted to such extreme environment by harvesting the glacier water. Impacts of climate change on biotic communities are usually associated with changes in the distribution of species at their latitudinal or altitudinal extremes and a temperature increase in last two decades showing a warming trend which is main driving force for the magnitude of optimum elevation shifts (Lenoir et al., 2008).

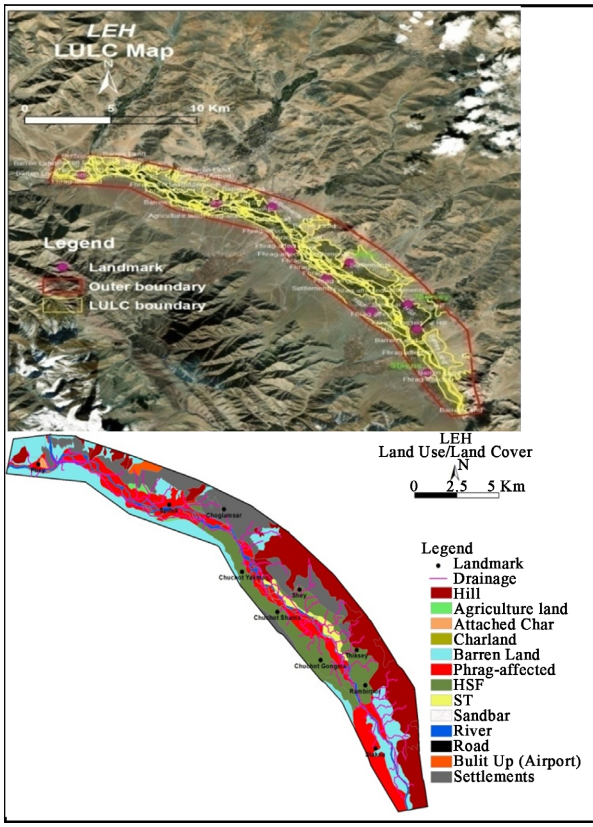
The investigation was conceptualized looking to the intensity and invasiveness of *Phragmites* in the wetland (river banks) *i.e.* non-cropped areas and also in association with seabuckthorn (SBT) and cropped areas around Thiskey, Palam, Lower Saboo, Stakna, Spitukand Chushot villages with a field share of 70:30 (Phragmites: crop ratio).

Distribution in Leh

The genus *Phragmites* of the family Poaceae comprises of the most common perennial, rhizomatous, stoloniferous, and tall (2.0 - 3.0 m) grasses, *Phragmites australis*. This transitional species of two closely attached ecosystems (*viz.*, aquatic and terrestrial) was first reported in India and it commonly occurs in marshy wetlands (Holm et al., 1991; Mal & Narine, 2004). In Ladakh, it is locally known as '*Dambu'* which has immense seed production potential and spreads vegetatively by a vigorous system of rhizomes and stolons. Seeds are also dispersed by wind during winters and are also spread by birds (Haslam, 1969). Currently, the whole Ladakh region along the Indus belt and lakes, extending from cold temperate regions to wetlands in Ladakh region along with the valleys, where water accumulates, supports the crops and weed growth in 1883.58 hectares area (**Figure 1**). It might have been disseminated accidentally during an exchange of adulterated seed materials, mud-brick and accidental transportation of its vegetative parts. It has expanded in large ares including wetland habitats of Ladakh region especially along the Indus River. Efforts were made to develop weed mapping for Leh region in respective villages using remote sensing and geographical information system (RS and GIS), high-resolution satellite data Sentinel data having 10 m resolution is used for land use and land cover mapping and Google-earth data having 1 m resolution is used for reference.

The Land use and land cover mapping revealed that the affected area with *Phragmites* is to the tune of 16.98 per cent (1883.58 ha) of the total area surveyed (**Figure 1**). This also includes the agricultural and non-agricultural lands of villages. Almost 99 per cent of the agricultural land and cultivable wasteland and river wetland were *Phragmites* infested.

While surveying, villages have apparently been bypassed by most weed endemics and explorations which enabled us to understand the weed menaces and their importance as fodder too. The reason for the weedy presence in cropped



LULC	Area (ha)	% Area
Attached Char	20.16	0.18
Built Up (Airport)	84.12	0.76
Charland	1.28	0.01
River	477.31	4.30
Road	4.30	0.04
ST	193.12	1.74
Agriculture land	67.26	0.61
HSF	1828.94	16.49
Settlements	1880.57	16.96
Hill	2646.27	23.86
Sandbar	14.28	0.13
Barren Land	1988.63	17.93
Phragmites affected	1883.58	16.98
Total	11089.83	100

Figure 1. Land use and land cover and *Phragmites* infestation along Indus plains in Leh.

areas is due to the high costs of labourers during cultivation along with an increased number of weeding at high altitudinal regions. It has been realised in the cold arid desert where scarcity of fodder makes equal credit for livestock as agriculture, this species was accepted as a substitute of fodder when thrashed along with the mature crops. Common reed (*Phragmites australis)* (Cav.) has also been observed along the banks wetlands, ditches, irrigation canals, seabuckthorn stands, brackish water, salt-affected areas and is a big menace in staple crops like wheat and barley. It grew more than 3 mitres when found associated with seabuckthorn shrub which is a potential shrub of cold arid region, supporting all vegetation including conserving soil and moisture therein. Due to seabuckthorn's extensive root systems (possessing nodules that fix nitrogen and improve fertility), wherever seabuckthorn was recorded near wet to semi-wet conditions, this invasive species (*Phragmites*) attained its height upto 3 metres as an associated species. In cropped areas, its height was about 1.5 to 2 metres while there was a significant reduction in height in salt-affected areas (Table 1).

Past studies have indicated that Dambu thrives well in soils of different pH, salinity, fertility and textures, and is able to attain significantly high productivity under diverse climatic conditions (Dinka & Szeglet, 1998). In Ladakh, it starts sprouting efficiently from last week of June depending upon the variations in temperature, soil nutrients and available oxygen (wetlands). Its rhizomes are buried deep in the soil up to 2 - 5 feet which protect it from frost and fire. High

transpiration rate growing under flood like conditions displays an adaptive feature which protects it from waterlogging during summers (Borin et al., 2011).

Phragmites seeds profusely and spreads vegetative *via* vigorous system of rhizomes and stolons which expands as long as 11 fts long as recorded in Chushot village (**Figure 2(a)** and **Figure 2(b)**) where farmers are in regular practice of excavating minimum 2 feet deep clay soil for preparation of mud-bricks for houses. Here, it was found beneath 2 - 4 fts soil crust layers and formed dense stands of monotypic communities upto one to two metres depending upon the infestation.

This view was supported by (Best et al., 1981; Hara et al., 1993; Marks et al., 1994). Farmers mentioned that if by mistake, the roots of reed get mixed in mud bricks, they remain alive and sprouts immediately when come in contact with wetness of the walls (**Figure 3(a)**). However, it was observed that it attains less height in saline area of Palam along the river bank (**Figure 3(b)**).

***Phragmites australis*: problem of cropped and pastoral systems**

T his weed has been recorded in wheat fields of Chushot and Palam areas where its presence was way much higher than wheat crop. This weed is location

Table 1. Density, height and yield of wheat under *Phragmites* infestation at varied soil types in various villages.

Phragmites australis	Stakna (Gravel land)	Chushot (Cropped area, salty/marshy land)	Palam (salty and marshy land)	Spituk (Cropped, salty/marshy land and semi-forest area)	Thiksey* (cropped and semi-forest area)
Density (per sq m)	26 - 30	38 - 42	45 - 48	13 - 17	-
Height (m)	1.3 - 2.0	1.5 - 3.0	0.8 - 2.0	0.56 - 1.3	2.0
Yield of wheat (q/ha)	3 - 4	4 - 5	4 - 5	1 - 2	13 - 14*
Soil type	Sandy-Sandy loam	Sandy to Clay loam	Clay loam slat affected	Clay loam Hard	Sandy to clay loam

*Normal wheat yield; **Near river bank.

(a) (b)

Figure 2. (a) Eleven feets long root of weed in cropped area when excavated in Chushot; (b) Separated dense root system from excavated soil.

(a) (b)

Figure 3. Severe infestation of reed in Palam village, Leh (a); less infestation in salt-marsh wetland in Spituk (b).

(a) (b)

Figure 4. *Phragmites* to wheat proportion is 60:40/70:30 in the cropped areas.

specific wherever its rhizomes and stolons are running. About 11 ft long root was recorded in Chushot area with the ratio of wheat: Dambu to be about 30:70 (in percentage) as shown in **Figure 4**.

Its extensive root system in wheat stand reduces wheat yield drastically. It is also well associated in sea buckthorn (SBT) stand due to superficial rooting nature of SBT (**Figure 5(a)**).

In the crop fields of Chushot, its height was more than crop height, thus suppressin the crop growth by 50 per cent (**Figure 5(b)**). However, in case of alfalfa fodder crop, is growth was suppressed due to extensive root system of alfalfa stand (**Figure 5(c)**). In Saboo, Umla, Stakmo, and Nang villages, at 3200 m asl, it has not been recorded significantly while in Saboo, it infested the barley crop with 80 (Reed):20 (barley) ratio. In Phey, Spituk and Thiksey villages at 2900 m asl, *Phragmites australis* dominated other weeds *like Chenopodium album, Malwaneglecta, Convolvulus arvensis, Setariaviridis, Cirsiumarvense, Fectusa*sp across the river banks. In case of non-cultivated land along the river belt *Phragmites australis was followed by Cirsiumarvense, Phragmites*sp *and Festuca*sp (preferred pasture grass) while in Seabuckthorn stands, Phragmites was followed by *Ambrosia artemisiifolia*, *Artemisia spand and Clematis*sp.

Phragmites invasion through allelopathy is not robust enough to provide reliable information that could integrate the existing knowledge to sound on-ground

reality. However, the fact cannot be overlooked as allelopathy is one of the mechanisms that might have helped successful invasion of some plant species. *Phragmites australis*, a ubiquitous wetland plant, has been considered as one of the most allelopathic and invasive species in the world (Uddin et al., 2012). Bel (2007) argues that weeds may elicit allelochemical biosynthesis in competing crops, as occurs in plant defence induced by disease and insect attack. It may also be attributed that effects of aqueous extracts of *P. australis* cause oxidative stress in cells of impacted seedlings that can result in cell death and ultimately inhibit the growth of plants and may lead to plant death due to presence of a chemical secreted by the roots of common reeds *i.e.* Gallic acid (3,4,5-trihydroxy benzoic acid) has been reported causing the cell death of native species (Rudrappa et al., 2007).

Photosynthetic intermediate and ecological behaviour in changing climate

P. australis is mainly a C_3 plant, however on the basis of habitats, four ecotypes of C_3 - C_4 photosynthetic intermediates have also been documented *viz*. C_3, C_4 species that evolve in swamp; C_3 - C_4 intermediate ecotype; C_3 species that evolve in dry land and C_3 - C_4 intermediate ecotype in saline environment (Zheng et al., 2000). Due to dual photosynthetic pathways in the species, it compete better to the changing environmental conditions (Srivastava et al., 2012). The ecological significance of *P. australis* has been realized worldwide as environmentally resilient species. The long growing period in most of the subtropical and mild temperate zones, facilitates reed plants to acquire all the essential adjustments to the fluctuations of temperature, nutrients and available oxygen in wetlands, together with certain physiological features such as transpiration rates in connection to the seasonal variations (Haslam, 1972). The staple crops of the Chushot village are seriously affected not only with its association but also by imbalancing the soil moisture level due to high transpiration that displays its better adaptive feature, protecting it from water logging during the summers and at mild temperate regions (Borin et al., 2011). Consequently, farmers have started utilizing it as a potential fodder for winter.

Possible management measures

Due to its extensive root network, this weed requires huge cost for its management. While eradication efforts are not affordable for the resource poor farming communities of Ladakh. Under such situation, the land management cost becomes very high and ineffective to combat this invasive weed, mainly in marshes. It is suggested that *Phragmites* may potentially be controlled by employing an affordable measure through livestock grazing. Recently farmers have become aware of its impact in reducing yield potential of crops, and hence demanding its control before the onset of sowing season. Being a climate resilient plant, it requires suitable remedial action in cultivated areas.. Below are the few management strategies of *Phragmites* in Leh:

- Deep ploughing and burning of its rhizones/stolons;
- Crop rotation;
- Being well adapted to the extreme environmental conditions like extreme

cold, warmth, dryness and wetness common reed can be successfully used for the treatment of industrial effluent and in faecal sludge treatments, as being used in Leh district.

- Good source of roughage for cattle and the fibres for making paper;
- Growing alfalfa in *Phragmites* infested areas.
- Herbicide application as pre-emergence (PE) or pre-plant incorporation (PPI) followed by burning can significantly reduce the abundance of Phragmites in wetlands.

Alfalfa: a potential solution for Phragmites reclamation

Alfalfa (*Medicago*spp L.) is one of the crucial fodder crop of Ladakh region due to its well adaptability to cold arid habitat. Decomposed alfalfa roots and their associated soil produced a 51% - 56% reduction in bladygrass seed germination. Root and shoot length of bladygrass seedlings were reduced by an average of 88%. Due to the presence of alfalfa. Decayed and undecayed mixtures of alfalfa roots and soil at 0.015:1 (w/w), inhibited bladygrass seedlings reproduce from rhizomes by 30% and 42%. It was found that root exudates of alfalfa seedlings caused significant reduction in shoot and root dry weights of bladygrass seedlings when alfalfa and bladygrass were grown together in nutrient culture (Rahman & Habib, 1989). In alfalfa stand, there was no *Phramgmites* recorded in alfalfa field (**Figure 5(c)**). It may be attributed that alfalfa might inhibit the rhizome-expansion due to its allelopathic effect as observed in case of bladygrass. Thus, it can be a potential biological solution for Dambu weed management in the region.

Phytoremediation nature

As removal of toxic heavy metals from the aquatic environment is one of the priorities of the researchers worldwide, this weed has high metal removal potential coupled with fast growth, thus accumulating metal in above and below ground biomass (Schierup & Larsen 1981; Szymanowska et al., 1999; Ye et al., 2003; Samecka-Cymerman & Kempers, 2001; Peltier et al., 2003; Windham et al., 2001; Ali et al., 2002; Mant et al., 2006; Chiu et al., 2006; Drzewiecka et al., 2010). That is why it has been the most preferred research plant for mitigating pollution from wastewaters, specifically in engineered wetlands. *P. australis* accumulates

(a) (b) (c)

Figure 5. Association of *Phragmites* and its spread (a)-(c). (a) Significant association with Seabuckthorn; (b) Assciation with crops-wheat and barley; (c) Emergence, affected in Alfalfa stand while in wheat there is complete infestation.

almost twice as high concentration of phosphorus and potassium in the below and above ground plant parts as compared to other emergent macrophytes, which help to remove excessive nutrient ions from environmental matrices (Singh & Srivastava, 2007).

It may also be utilised as an experiment for phytoremediation of heavy metals in First Faecal Sludge Treatment Plantin the world at an altitude of 11,400 feet at Leh.

Common reed has recently been utilized for removal of heavy metals in Leh sewerage water plant particularly for making water utilizable for high altitudinal condition where water scarcity is a major issue (**Figure 6**).

As feed and fodder

Being a strong soil binder and a fodder alternative, *Phragmites* can be used to prevent rivers and canal erosion (Bonham, 1983). It is a major harvested resource for thatch and other traditional crafts. It is used for pulp production in some countries like Romania, in the Danube delta. It is cultivated as a crop in Northern China (Li & Cao, 1981). *Phragmites* stands play a major wildlife support value in temperate wetland areas. Being a vital part of the wetland ecosystem, it supports wildfowl and other animals (Dely-Draskovits et al., 1992). The sun-dried *Phragmites* grass as well as its plant parts can be considered as a source of high-fibre feedstuff, interesting to supply low digested fibres (cellulose) and lignin (**Table 2**).

Figure 6. Faecal Sludge Treatment Plant in Leh using *Phragmites.*

Table 2. Nutritive value and potential use of sun-dried common reed (*Phragmites australis*).

S. No.	Identity	Plant part	villages	Ash	OM	AIA	CP	NDF	ADF	Hemi-cellulose	Lignin	Cellulose
1	Mature grass	Whole plant	Palam	8.1	91.9	4.6	5.8	71.1	40.0	31.1	2.0	38.1
2	Mature grass	Leaf	Palam	12.9	87.1	4.1	6.0	67.8	35.0	32.8	10.6	24.4
3	Mature grass	Stem	Palam	4.1	95.9	1.5	5.1	70.2	54.5	15.7	1.7	52.8
4	Grass	Panicle	Palam	10.5	89.5	3.3	4.0	68.0	32.4	35.6	1.6	30.8
5	Grass	Whole plant green	Palam	2.5	97.5	1.3	4.9	70.6	39.0	31.7	0.2	38.7
6	Grass	Whole plant	Chushot/Stakna	11.3	88.7	2.7	4.8	69.9	41.0	28.9	2.9	38.2
7	Grass	Whole plant	Palam	21.1	78.9	4.4	8.2	76.5	41.7	34.9	2.8	38.8

OM-Organic matter; NDF-Neutral Detergent Fibre; Acid Detergent Fibre (ADF); CP-Crude protein.

4. Conclusions

Phragmites australis, a perennial and emergent aquatic plant with C3 - C4 photosynthetic ecotype, is impacting the cropped and non-cropped vegetation intensities of Leh-Ladakh by reducing the yield up to 50 percent. Its dense rooting has been observed 2 - 3 feet below the ground level and is difficult to eradicate due to presence of its roots in deeper soil. Due to its intermediate plant growth habit, *Phragmites* becomes a climate-resilient species of cold arid climate of Ladakh. Its invasion has now become a serious issue not only for farmers but also for defence. Today, it has become a major ecological threat for agri-silvi-pastoral system and biodiversity due to its expansion in cropped lands including many wetlands and salt-affected habitats of cold arid region. It is important to make people aware of this problem, in order to monitor the invasion sites, and manage it by physical removal along with the belowground rhizomes. Using the systemic herbicides with careful follow-up, will also help its suppression in small areas, thus allowing native plants to re-establish. Its use as fodder integrated with other useful grasses should be investigated for better utilization as an indirect management. Crop rotation of wheat with alfalfa fodder is the need of the hour for the suppression of *Phragmites* in the region.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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