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Short communication

Drying Willow (*Salix fragilis* L.) Population Under Agroforestry System in Cold Desert Region of trans-Himalaya: a Possible Consequence of Repeated Vegetative Propagation

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ABSTRACT
Willow (*Salix fragilis* L.), a multipurpose tree introduced about 150 years ago in Lahaul, a part of cold desert in trans-Himalaya, adapted well under agroforestry system. The species was propagated by vegetative means throughout the region and it immensely contributed to the socio-economic status, ethno-botany, ecology and greenery of the cold desert. It proved to be a "wonder species" or "the life line plant" for the people and often cited as the best examples of agroforestry system in the Himalayan cold desert. Unfortunately, willow trees (*S. frgilis*) are drying in the region; above 80% mortality was recorded and is continuously increasing. Efforts from local people and by certain research institutes have been put forward but, no significant change was visible. Few reports indicated possible role of aphid infestation, fungal disease, monoculture plantations, old planting stocks and changing environmental conditions for the current population status. However, controlled studies are lacking to confirm the same. We discussed here in detail about the possible role of repeated vegetative propagation from same gene stock for many generations, which directly or indirectly responsible for the current population status. Introduction of new and improved varieties is recommended.

Key words: Himalayan-cold-desert, Lahaul, Vegetative propagation, Willow mortality

INTRODUCTION

Twenty five *Salix* species have been known to be reported in the Indian Himalayan region. Among them, 10 species can be found growing in Lahaul; a part of cold desert area in trans-Himalaya (Aswal and Mehrotra 1994). Owing to cold desert conditions (typically xeric, poor and scanty rainfall, huge snowfall, extremely fluctuating temperature regime) only two species (*Salix alba* L. and *Salix fragilis* L.) can be found to thrive better and adapted well in cold desert conditions as compared to other species (Rawat et al. 2006, 2009). *S. fragilis* was known to be introduced in the region about 150 years ago by Britishers, and due to its well adaptation in cold desert conditions, multiple uses, medicinal importance, easy propagation, rapid growth and high biomass production, have made the species popular among the habitants of Lahaul and the species has been extensively cultivated under agroforestry system in Lahaul (Vishvakarma et al. 2005). The latter, immensely contributed to the greenery of cold desert (Fig. 1, 2A) and often cited as the best example of agroforestry systems in the Himalayan cold desert. The species is considered as a poor men timber and is closely associated with the socioeconomic status and development of the region where, it proved to be a study source of wood production for minor timber, fuel wood, agricultural implements, basket making, household utensils etc. (Sharma et al. 2011). The species also play environmentally important roles as, wild habitat, soil erosion control, restoration of natural river-bank environments, phyto-remediation of heavy metal toxicity, soil remediation, carbon sequestration and reverse or reduces the effects of climate change and air pollution (Ku et al. 2019). *Salix* is well known for its uses in traditional health care systems and is the original source of salicylic acid (a precursor of aspirin), used for years to ease joint pain and control fever (Mahdi 2010). It is also a valuable source of many biologically active compounds including simple phenols, phenolic and

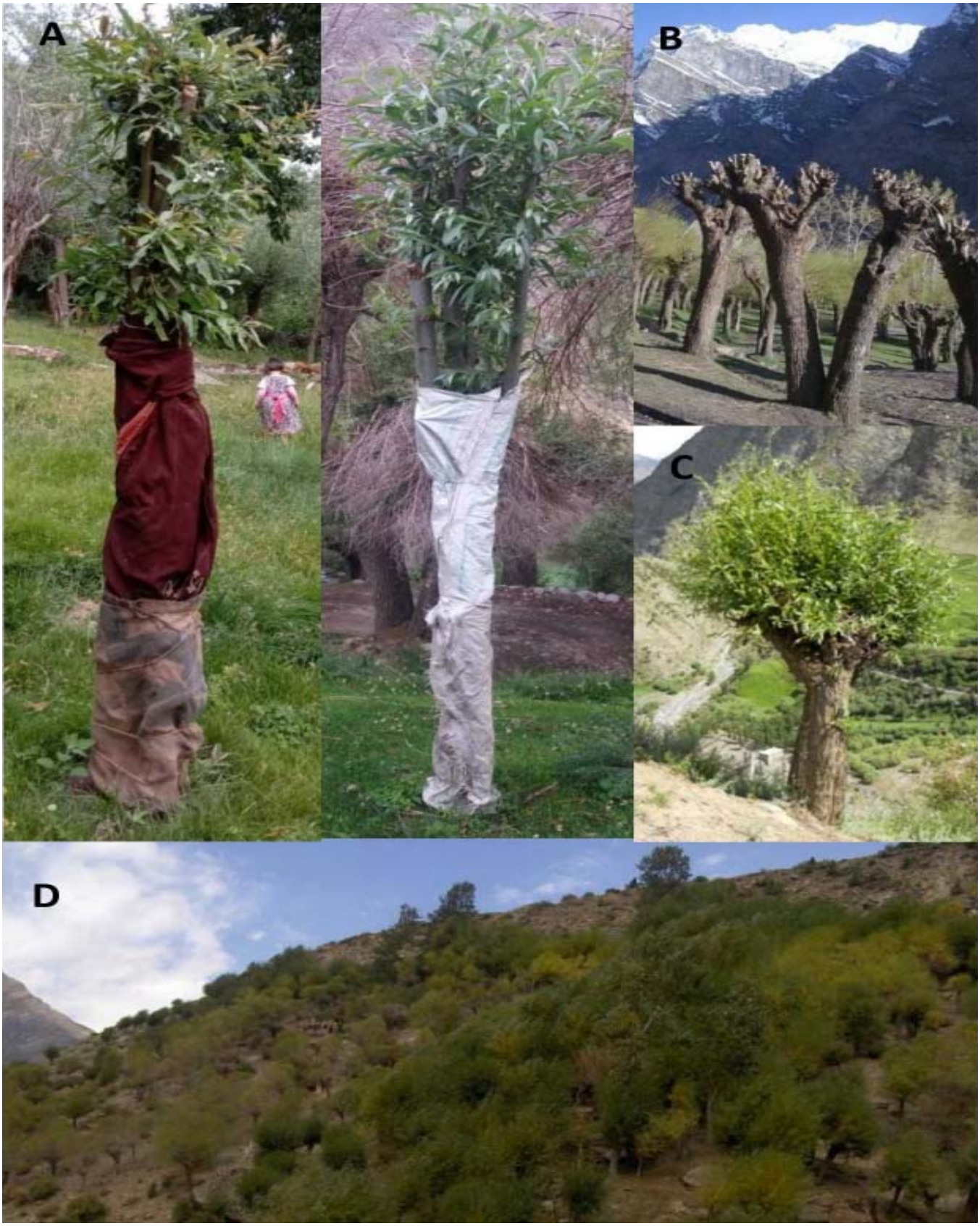

Figure 1. Different stages of willow (*Salix fragilis* L.) under agroforestry system in Lahaul: (A) vegetative propagation through shoot cuttings, wrapped with old cloths to avoid peeling off by livestock's, (B) pollarded trees, (C) fresh shoots after six months of pollarding, and (D) a landscape showing willow population during 2005-2008

Figure 2. *Salix fragilis* population under agroforestry system in Lahaul: (A) healthy, (B) dried and (C) wood borer infestation in drying willow

non-phenolic glycosides, flavonoids, organic acids, lignans, sterols and terpenes. Various pharmacological experiments have convincingly confirmed the analgesic, anti-inflammatory, anticancer, antidiabetic, antioxidant, antimicrobial, antiobesity, cytotoxic, hepatoprotective and neuroprotective activities (Tawfeek et al. 2021).

Agroforestry is a sustainable land management system where, agriculture and pastoral operations are integrated with woody perennials in farm and rangeland to maximize production, diversify local products and economies, sustain socioeconomic and cultural stability, secure food and livelihood, improve micro-climate and landscape, and strengthen environmental benefits (Brown et al. 2018, Dar et al. 2018). Unfortunately, willow trees (*S. fragilis*) under agroforestry system in Lahaul are drying and the mortality rate has been reached to an alarming level and is continuously increasing. According to the local habitants, the drying of willow was first observed about 20 years ago, and slowly spread to the entire Lahaul valley. Currently, only few trees are standing green, and if the prevailing scenario continues, the species will be wiped out very soon from the region. The loss of such an important and multipurpose species would have far reaching consequences particularly on the socio-economic status of local habitants and on environment generally. Some efforts from local people and by certain research institutes have been put forward to save the species but, no significant change is visible. Therefore, the present manuscript reports the current population status, concerns, causes, and possible cure/remedy and has been discussed in detail.

MATERIALS AND METHODS

Study area

The study area, Lahaul lies between latitudes 31° 44' 34" to 32° 59'57" N and longitudes 76° 46' 29" to 78° 41' 34" E at an altitude between 2800-3000 m asl in the district Lahaul-Spiti of Himachal Pradesh, India. The area comes under a vast rain-shadow zone and is a part of cold desert region in trans-Himalaya. The area receives poor precipitation during summer and huge snow fall in winter (the total annual rainfall is about 606.8 mm) with temperature extremes (-17.7 to 26.8 °C recorded in the month of January and July, respectively). The average annual minimum and maximum temperature is -5.5 and 17.9 °C.

Data collection and analysis

The study was conducted during 2017-2020 at six different locations (Tholang, Lote, Kirting, Thapak, Shansha and Jahalma) in Lahaul, representing major part of the willow population in the area. Fifty trees/ site and 3-sites/ location were observed to count the number of healthy, drying, completely dried, and infestation if any. Habitat specific (moist places: near water sources; frequently irrigated places; and comparatively dry places) differences in population status were also recorded. In parallel, information about the willow cultivation, propagation, uses, drying history were also recorded from the local habitants through verbal communication and questionnaire. The data were expressed as mean percentage value ± s.d. The statistical differences were calculated based on the Student's *t*-test, wherever required.

RESULTS AND DISCUSSION

A species of willow (*Salix fragilis*) which had become the part of agroforestry, socioeconomic culture and eco-system of Lahaul; a part of cold desert region in trans-Himalaya has been drying since past few years. Hundreds of dried and drying willow tree population can be found standing everywhere in Lahaul valley (Fig. 2B). The present study revealed a large scale mortality of *S. fragilis* in the valley. Where, above 80% trees completely dried, 11% are drying and only few trees were found healthy (Table 1). The multi-purpose willow species, which is used by local habitants to feed livestock, as firewood, minor-timber, making baskets, agricultural implements, household utensils, plays significant role in controlling landslides, snow avalanches etc., has almost entirely diminished. Efforts at local level and suggested remedies from few research institutes could not help people to protect the trees.

Rawat et al. (2006) observed only few drying *Salix* trees while, Sharma et al. (2011) reported 20-30% mortality. We recorded significantly higher mortality (above 80%) in the present study. Previous reports (Rawat et al. 2006, Sharma et al. 2011) hinted towards aphid infestation, fungal disease, monoculture plantations, old planting stocks,

Table 1. Status of willow (*Salix fragilis* L.) population under agroforestry system at different locations in cold desert area of Lahaul. The data are average of three sites/location ± s.d. #only observed in drying and dried trees. *The differences are significant at $P \leq 0.05$.

Village/ location	Willow population (%)			Infestation (%)	
	healthy	drying	dried	Aphids	Wood borer#
Tholang	07 ± 2	12 ± 5	81 ± 4	48 ± 7	49 ± 7
Lote	12 ± 6	14 ± 2	75 ± 7	34 ± 6	53 ± 6
Kirting	11 ± 2	09 ± 6	80 ± 3	42 ± 11	61 ± 4
Thapak	09 ± 3	07 ± 3	85 ± 8	38 ± 8	66 ± 3
Jahalma	08 ± 2	09 ± 3	80 ± 6	28 ± 4	44 ± 8
Total*	**09 ± 2**	**11 ± 3**	**80 ± 3**	**38 ± 7**	**55 ± 8**

Table 2. Mortality rate in willow (*Salix fragilis* L.) population under agroforestry system at different habitat and locations in cold desert area of Lahaul. 40 to 60 trees were observed/habitat or location depending upon the availability and expressed in percentage ± SD. *significantly different ($P \leq 0.05$).

Sites/ locations	Willow mortality rate (%)		
	Moist places	Irrigated sites	Drier places
Tholang	68	82	88
Lote	72	85	100
Kirting	83	79	94
Thapak	65	88	100
Shansha	77	83	94
Jahalma	81	76	89
Average*	**74 ± 6.57**	**82 ± 3.89**	**94 ± 4.71**

decrease in water flow, wrong choice of planting sites, rise in temperature, melting of glaciers and decrease in snowfall among the possible causes of willow mortality in Lahaul. However, controlled study or appropriate scientific proof to establish the same is lacking. According to the local habitants, aphid attack on *Salix* species in Lahaul has long been known and depending upon the prevailing environmental conditions (temperature, humidity), the intensity of infestation changes but, such mortality due to aphids has never been reported or observed earlier. Above 78% respondents did not agree with the said reason as the mortality was also observed in trees with minor or without any aphid infestation (Table 1). Therefore, aphid infection being the reason for the large scale willow mortality in Lahaul cannot be fully accepted and a controlled study is needed to establish the same. Among the other reasons such as, wrong choice of planting sites, decrease in water flow can also be easily ruled out as the drying of willow was observed in all sites including, moist (74%), frequently irrigated (82%) and comparatively dry places (94%) (Table 2). Although, significant habitat specific differences were observed. Rise in temperature, melting of glaciers and decrease in snowfall are global issues and their direct or indirect effects can be possible. However, such a drastic impact on a single species, in such a short period of time which otherwise having invasive features with high adaptability in diverse range of environmental conditions (Budde et al. 2011, Isebrands and Richardson 2014). In the present study, 55% dried and drying *Salix* species were found to be infested with wood borer (Fig. 2C, Table 1). The latter was not established whether borer caused drying or vice-versa.

Monoculture plantation, vegetative propagation and old planting stocks in *S. fragilis* propagation in Lahaul is completely true and is well confirmed by the local habitants. The current *S. fragilis* population in Lahaul trace their ancestry back to the common stock or first few plants introduced/imported about 150 years ago (Rawat et al. 2006). They were raised and propagated throughout the Lahaul by repeated shoot propagation and hence, the entire population share same genetic makeup. The innovative farmers or habitants have evolved, standardized and successfully practiced the methods of vegetative propagation of *S. fragilis*. Where, selected 3 or 4 year old, healthy pollarded shoots (3 to 5 in number) tied together (Fig. 1A) are used for plantation in a single pit (70 to 80 cm deep and 50 cm wide). The planted shoot cuttings are further properly covered or wrapped with old cloths or gunny bags or tin covering or with thorny bushes of rosa (*Rosa webbiana* Wall. Ex Royle) and sebuckthorn (*Hippophae rhamnoides* L.) at basal portion to avoid peeling off the thick, green and fleshy bark, by livestock's and grazing animals (Fig. 1A). Plantation is done mainly in the month of March-April, when the soil moisture become appropriate due to melting of snow and weather conditions become conducive after the harsh winter months. Sprouting in shoot cuttings starts within a month. The trees are pollarded during winter

months after every 3-4 years and the resulted twigs and green fleshy bark of the thick branches serve as the only source of green fodder during the harsh winters.

Vegetative or macro-propagation has some specific advantages and disadvantages as well. The method is consistent, fast, and produce genetically identical off springs with exactly same traits as their parents. Therefore, advantageous traits can be easily preserved (Leaky 2014). However, on the other side, it prevents species genetic diversity which can lead to increased susceptibility to surroundings (pathogens, insects and environmental conditions) that can wipe out the entire population (Dick and Leaky 2006, Leaky 2014). The latter holds true in case of the present *S. fragilis* population. Where, more than 80% trees are dried and the rate of mortality is continuously increasing. Besides susceptibility, continuous vegetative propagation from a single stock for many generations ultimately leads to loss of vigor and cell death in due course of time. Cells cannot remain viable indefinitely, ageing occurs, albeit slowly, and eventually leads to cell death after a period of time or number of divisions, due to many reasons including free radical dependent cellular damage and/or mutations (Sharma et al. 2014, Smirnoff and Arnaud 2019). Free radicals (FR) or reactive oxygen species (ROS) are often implicated in ageing processes. All cellular constituents including DNA, RNA, proteins, lipids and carbohydrates are potential targets of ROS (Wang et al. 2015, Sharma and Sharma 2017, Nagel et al. 2019). The accumulation of FR or ROS beyond certain level cause significant oxidative damage to the cellular constituents and results in the loss of vigor, increased vulnerability and ultimately cell death. Such effects will be more pronounced in vegetative propagated cells as they carry the oxidative damage already occurred/accumulated in parental cells. So, longer the vegetative propagation more oxidative damage and mutations can accumulate. Further, the loss of rooting ability in vegetative propagation due to "Phase Change" or ontogenetic aging in perennial plants is known (Leakey 2004). Phase change occurs during gradual transition of plants from the juvenile phase of vegetative growth to a phase of sexual maturity with increasing size and structural complexity (Dick and Leakey 2006). The high mortality rate among all age groups of *S. fragilis* population and spread of disease only in a single species among closely related species of same genus strongly supports the above reasons. According to local habitants, the life span of a willow tree in the region is about 125 years and one can easily notice such old willow trees with large hollow trunk and reduced productivity in the area. Thus, the entire population appears to attain its maximum age since its introduction in the region (150 years ago) and hence, directly or indirectly responsible for the current population status.

Further, constrains in sexual or seed based propagation in *Salix* species due to tiny microscopic seeds with rapid viability loss (within a fortnight) and/or shorter seed longevity (Maroder et al. 2000, Wood et al. 2003, Ku et al. 2019) also be the reason for dominance of vegetative propagation and hence poor genetic variability or increased susceptibility within population.

CONCLUSIONS

Agroforestry is a sustainable land use system that combines trees and/or shrubs intentionally with crops and/or livestock to enhance production and optimize the benefits (Bhat et al. 2019). *Salix fragilis*, a multipurpose tree species under agroforestry system in Lahaul, generally referred as "wonder plant" or "life line plant" of Himalayan cold desert is under extreme threat due to drying up of above 80% population. The continuous vegetative propagation from a single gene stock for many generations led to poor genetic variability and increased susceptibility seems to be directly or indirectly responsible for the current population status. The observations strongly indicate the importance of genetic diversity and hence new and improved varieties should be introduced at regular intervals in such populations. The current observations alarms and/or is a lesson for other plant populations raised through similar practices elsewhere.

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Conflict of Interest: The authors declare no conflict of interest

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