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LOCAL COMMUNITIES' PERSPECTIVES ON ECOLOGICAL RESTORATION OF NATIVE PLANT SPECIES: EVIDENCE FROM DELHI'S SOUTHERN RIDGE

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Abstract

Human activities and natural disturbances have significantly damaged ecosystems, resulting in a loss of biodiversity and creating a need for ecological restoration. Urban forests, in particular, are impacted by invasive species such as Prosopis juliflora, which compete with native species and disrupt ecosystem functions. Although introduced for benefits like fuelwood and desertification control, these species have turned into harmful invaders. Restoration efforts require balancing local biodiversity needs with societal values and managing conflicts among stakeholders. Understanding community perceptions of ecosystem services and disservices is crucial for effective management. This study investigates local perceptions of communities near Delhi's Southern Ridge regarding *Prosopis juliflora* and the willingness to pay for its biological control. Using principal component analysis (PCA), the study identified six ecosystem service (ES) and three ecosystem disservice (EDS) bundles. ES bundles were categorized using the Common International Classification of Ecosystem Services (CICES), while EDS bundles followed prior studies. The results revealed connections between biodiversity, recreational activities, and disservices such as poor visibility and connectivity. The findings also highlighted trade-offs between provisioning and regulating services, with gender-specific impacts on connectivity and accessibility. The mean and median Willingness to Pay (WTP) for ecological restoration of native plant species was also calculated for different scenarios, showing an increasing trend in mean WTP with more conservation, while median WTP showed fluctuations depending on the potential economic impact of eliminating *Prosopis juliflora.*

Keywords: ecosystem services and disservices, ecological restoration, invasive plant species, Prosopis juliflora, contingent valuation method, urban biodiversity

JEL Classification: Q57

Contents

1. INTRODUCTION

Anthropogenic and natural disturbances on forest lands have altered their "natural adaptive capacity," leading to extinction or damage to local ecosystems and/or native species (Keenan 2015; Hess, Mesléard, and Buisson 2019), which are crucial in enhancing biodiversity value. The ever-growing demand from humans has resulted in the depreciation of ecosystems, leading to the degradation of approximately a quarter of the total land.[1] Therefore, ecological restoration of biodiversity becomes an important objective under the overall goal of sustainable development. Ecological restoration, defined as "the process of assisting the recovery of a degraded ecosystem to reflect inherent values and provide goods and services valued by people" (Fischer et al. 2021), becomes crucial under the broader framework of sustainable development.

Restoration has gained global attention, with the UN declaring 2021-2030 as the "Decade on Ecosystem Restoration" and the goals for restoring terrestrial and marine ecosystems featuring prominently in the 2030 Sustainable Development Goals (Gann et al. 2019). Deterioration of the ecosystem (due to anthropogenic pressure and climate change) acts as a motivation for ecological restoration, but what drives the process are conflicting societal values (Lackey 2001, cited in Stanturf et al. 2014) and livelihood requirements (Stanturf et al. 2014).

Urban forests are composed of diverse microhabitats supporting extensive flora and fauna. These microhabitats have specific conditions like sunlight and humidity that support particular organisms (DFW 2022a). Ecosystem recovery of these microhabitats can be either passive—stopping human activities like grazing, or active—involving human intervention through direct participation or nongovernmental organizations (Clewell and Aronson 2006; Holl and Aide 2011). Over time, the vegetation type, especially in the Aravallis in India, has transformed into "an artificial vegetative mixture" due to the introduction of exotic species (DFW 2022a) that coexist and compete with native species for natural resources. Such plants are referred to as "naturalized" plants, which have adapted to the local ecosystems (DFW 2022a) and biophysical conditions despite being introduced from a foreign[2] region. These include invasive species like Prosopis juliflora and Lantana that can inhibit the healthy development of native ecology (Hess, Mesléard, and Buisson 2019; DFW 2022b).

Invasive alien species are "non-native species that threaten ecosystems, habitats or species" (CBD 2008, cited in Pejchar and Mooney 2009) and are often considered as ecosystem disservices as they reduce security, health, and social relationships that constitute human well-being (Mooney 2005; Hanley and Roberts 2019). Alien trees are introduced in order to meet the increasing demand for timber and other material benefits (Dodet and Collet 2012, cited in Naudiyal, Schmerbeck, and Gärtner 2017) but not limited to biomass-derived services and are often introduced for reforestation of damaged sites (Naudiyal, Schmerbeck, and Gärtner 2017) and to limit desertification beyond acceptable thresholds (DFW 2022a). However, sometimes, these alien introductions turn into "aggressive" invasions (Hussain et al. 2021), altering the composition and structure of native ecosystems (Naudiyal Schmerbeck, and Gärtner 2017). According to United Nations Intergovernmental Platform for Biodiversity and Ecosystem Services (IPBES), invasive species threaten approximately 20% of the

[1] Details available at https://www.unep.org/gef/focal-areas/land-degradation.

[2] "Foreign" refers to any region outside of the local habitat and it should not be confused with geographical boundaries.

Earth's surface, including biodiversity hotspots (IPBES, 2019, cited in Rai and Singh, 2020).

Ignoring the economic impacts of invasive alien species might result in an "invisible tax" on the supply of ESs (Pejchar and Mooney 2009). Invasive species can alter the biophysical conditions of local habitats like soil erosion rates and extreme weather events regulations in their favor, making it less favorable for the native species (MA 2005; Vilà et al. 2010). Even a single invasive species can drastically change ecosystem functions due to its impact on species richness (MA 2005). Along with biodiversity loss (Pyšek et al. 2020), a decline in ES supply can cause multiple economic losses such as detrimental impacts on agricultural yield, damage to infrastructure (both residential and commercial), disruption of the flow of water (for drinking, irrigation, and other purposes) and increase the risk of fires (both in terms of intensity and frequency) (MA 2005). In the People's Republic of China, Xu et al. (2006) estimated damage to ecosystem processes and functions as "indirect" losses and damage to agriculture, infrastructure, etc., as "direct" losses. Total direct losses were estimated to be approximately US$2397.39 million (agriculture and human health accounting for 61.48% and 14.72%, respectively) and indirect losses were estimated to be US$12056.58 million (Xu et al. 2006), suggesting that indirect losses were US$4.03 million higher than direct losses.

However, not all invasions negatively impact ecosystem functions and services. Sometimes, a loss in biodiversity due to invasion can negatively influence native ecosystems' ability to deliver ESs but might not imply a loss in overall ES delivered. For example, Vilà et al. (2011) found that while invaded areas reported biodiversity loss, a single productive species could sustain ES supply. The success of restoration efforts depend on the environment's susceptibility to invasions and the interactions between the invader, native species, and the biophysical conditions (Lonsdale 1999; Hess, Mesléard, and Buisson 2019). Trade-offs and synergies emerge from these interactions causing conflicts among stakeholders involved in restoration (Potgieter et al. 2017). Therefore, restoration policies should be based on the estimation of losses or extinction of local biodiversity and values attributed to ESs and EDSs by local populations compared to global threats (MA 2005).

Prosopis juliflora holds significant economic and ecological value in arid and semi-arid regions worldwide, however its introduction has led to the invasion of native biodiversity due to its fast growth (Linders et al. 2020). Introduced to arid regions for fuelwood, fodder, and desertification control (Dayal 2007; Laxén 2007), it has since invaded beyond its natural threshold, affecting biodiversity and ecosystem functions. For instance, it threatens tiger habitats in Ranthambore and groundwater recharge in Delhi Ridge (DFW 2022b).

Despite growing research on ecosystem services and trade-offs, practical, insights into managing people's perceptions of ESs during restoration efforts remain scarce. Only few studies have integrated local perceptions of ecosystem services with management strategies. Understanding these perceptions is crucial for optimizing trade-offs, as well as for identifying appropriate policies or compensation mechanisms. Social valuation can be a valuable research tool, in this context, enabling the assessment of local perceptions of ecosystem services and the trade-offs between native and invasive species.

This paper aims to examine how local communities near a protected area of Southern Ridge in Delhi, India perceive ecosystem services and disservices provided by *Prosopis juliflora*. It explores how these perceptions influence the willingness to pay for biological control measures aimed at restoring native biodiversity by controlling or eliminating *Prosopis juliflora*.

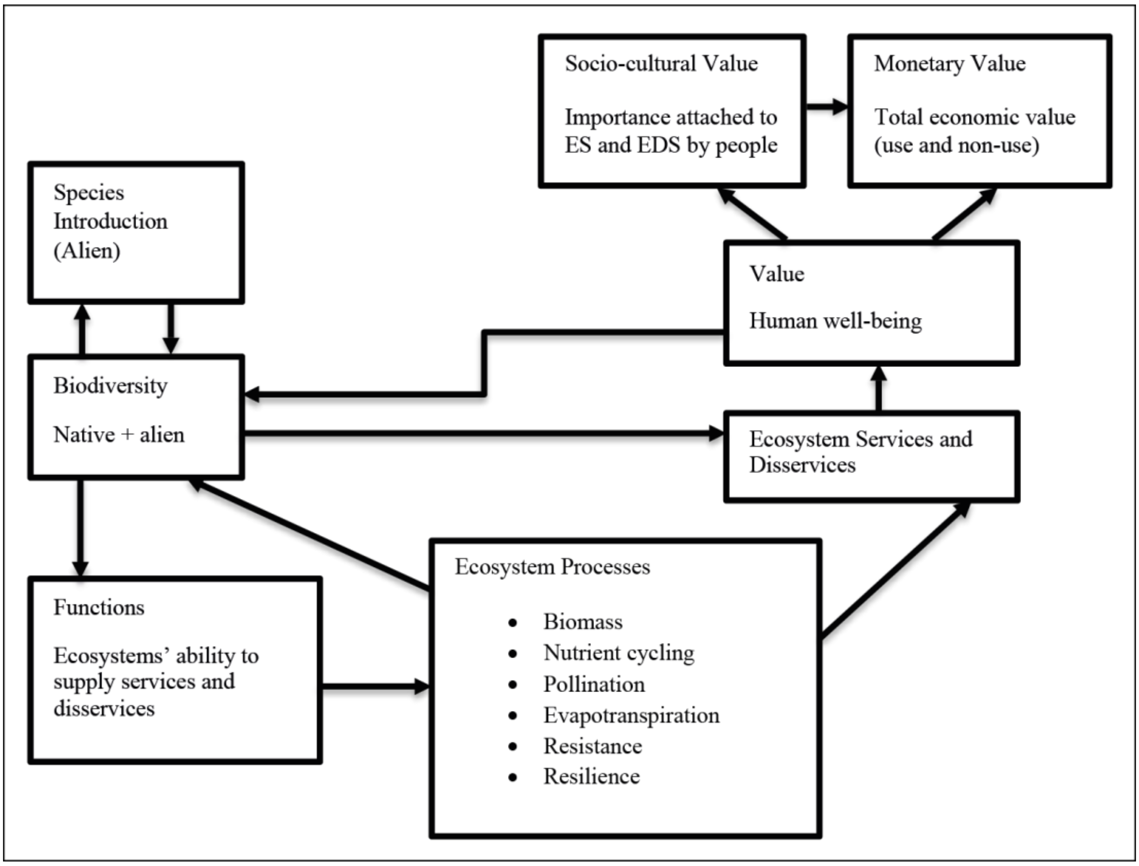
2. METHODS

2.1 Conceptual Framework

The conceptual framework for the study is summarized in Figure 1. It shows that alien species are introduced into the ecosystem to improve the ecological conditions and biodiversity. Such introduction of the alien species brings adverse consequences along with benefits. Therefore, this study empirically addresses the following research objectives:

1) To identify and derive bundles (sets frequently identified) of perceived ESs and EDSs and examine trade-offs and synergies between them.
2) To estimate the mean and median willingness to pay (WTP) to eliminate or control the invasive species, *Prosopis juliflora*, through its biological suppression
3) To examine the impact of bundles of the perceived supply of ESs and EDSs by *Prosopis juliflora* on this WTP for its biological suppression.

Figure 1: Conceptual Framework

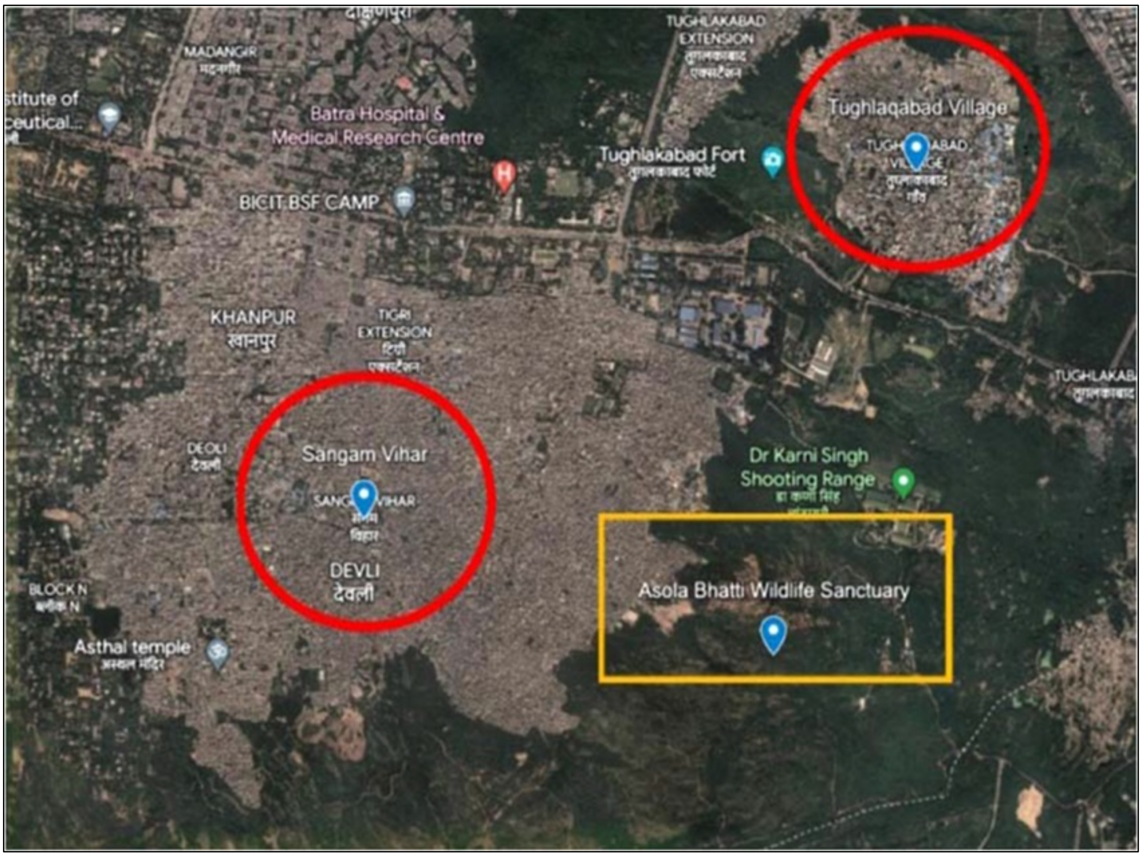


Source: Adapted from MA (2005) and Martin-Lopez et al. (2014).

2.2 Study Area

This study was carried out in two localities (lying in a radius of < 5 km), namely Sangam Vihar and Tughlakabad, in proximity to Asola Bhatti Wildlife Sanctuary (AB-WLS) as shown in Figure 2, located in the South Delhi District (28° 24′ 52″–28° 29′ 45″ N and 77° 11′ 32″ –77° 16′ 13″ E). The sampling distribution is shown in Table 1 The Forest Survey of India (FSI; 2021) reported that the South Delhi district has the maximum forest cover area (among all districts) of 84.64 sq. km (34.27% of the district's geographical area) and saw an increase of 0.01 sq. km (as compared to the 2019 assessment) (DFW 2022b). Along with the maximum total forest cover, South Delhi also ranked highest in terms of density of forest coverage (FSI 2021). AB-WLS was notified as a protected area in 1986 and covered most of the Southern Ridge (Chopra, Singh, and Khuman 2022) with a total area of 1972.93 Ha (DFW 2022b).

Figure 2: Localities around AB-WLS: Sangam Vihar and Tughlakabad



AB-WLS is the only protected area in the urban conglomeration at the Delhi–Gurgaon–Faridabad border and represents the "green lungs" acting as carbon storage grounds for densely populated Delhi and Haryana's neighboring areas (Sinha 2014). The Delhi Ridge has four physiographic divisions: Khadar (associated with rivers), Bangar (irrigated area), Dabar (low-land rain-fed areas), and Kohi or Pahari (associated with hillsides). AB-WLS and its surrounding areas fall under the Kohi or Pahari division, which has rocky and undulating areas (Sinha 2014). The soil is sufficiently permeable and acts as an aquifer for Delhi's groundwater recharge (DFW 2022b). The average annual precipitation is estimated to be 617 mm, and the rainy season usually falls between June and September (Ganguly and Chauhan 2018). Southern Ridge experienced heavy damage due to the extensive mining of quartzite called “Badarpur” (Sinha 2014). There was severe exploitation of the grounds by livestock for resting and grazing purposes, which further degraded the landscape. To put a stop to this degradation and to preserve the biology and ecological functions, mining was gradually halted, and the Asola and Bhatti mine areas together constituted the Asola Bhatti Wildlife Sanctuary under the Wildlife (Protection) Act, 1972 (Sinha 2014) in October 1986. This land was consolidated from Asola, Sahurpur, and Maidan Garhi villages. After the imposed ban on Badarpur mining, an additional 2,166.28 acres of land was acquired from Bhatti village and was incorporated into AB-WLS under Section 18 of the Wildlife (Protection) Act, 1972 in April 1991, making it a total area of 4,845.57 acres (Sinha 2014).

Table 1: Sampling Distribution

	Sample		Population	
Wards of the Study Region	**Nos**	**%**	**Nos**	**%**
Sangam Vihar-A	77	42.8	62,786	41.1
Tughlakabad	103	57.2	89,899	58.9

Source: State Election Commission.

2.3 Eradication of *Prosopis juliflora* using Biological Suppression

Prosopis juliflora in the Delhi Ridge appears as a woody tree with yellow flowers (DFW 2022a). It is highly drought-resistant and competitive with the existing native vegetation. It was introduced to prevent the desertification of the Thar Desert to alarming levels and was also a source of fuelwood in peninsular India (DFW 2022a). It is one of the top five tree species inside ‘Recorded Forest Area’ in Delhi, with the highest distribution in each diameter class of 10–30, 30–60, and >60 (FSI 2021). It also ranks the highest ‘Trees Outside Forest’ in the rural areas of Delhi, with a relative abundance of 29.52%, and second in urban areas, with a relative abundance of 8.11% (FSI 2021). In addition, it is one of the major invasive species with the highest spread, with an estimated extent of 3 sq km (FSI 2021).

A lot of the vegetation grown in the local microhabitats of Delhi Ridge consists of slow-growing native plants like *dhau or palash*, which have not been able to compete with the fast-growing invasive species like *Prosopis juliflora*. Hence, control of *Prosopis juliflora* should cater to both these features, i.e., inhibit the growth of the invasive tree while promoting the growth of fast-growing native trees. One such technique is referred to as the “biological suppression of the invasive tree,” where sunlight and nutrient supply to a mature tree is withdrawn, and the tree is pruned for its vegetative growth while a mix of native vegetation comprising of fast-growing trees, shrubs, and creepers are planted in the neighborhood of the suppressed tree (DFW 2022a). In the restoration project at AB-WLS, damaged native vegetation and/or microhabitats of the Aravallis, like *dhau or palash*, are being recreated through the biological suppression of *Prosopis juliflora*. The process is briefly explained in Table 2.

Table 2: Biological Suppression of *Prosopis juliflora*

Mature Trees of *Prosopis juliflora* Replaced by Native Plants	
Nursery Treatment of Native Plants	**Suppression of Invasive Species**
• Seed procurements • Conducive temperature maintenance in the polyhouse • Temperature adaptations in greenhouse • Natural growth in beds	• Slowly killing off sunlight and nutrient supply of mature tree • Tree pruned for its vegetative growth. • Fast-growing native trees and shrubs planted in close quarters

Source: Adapted from DFW (2022a).

2.4 Ecosystem Services and Disservices

Resilience from invasion is itself considered as one of the ecosystem services produced because of the interaction between biodiversity and ecosystem processes and functions (MA 2005); however, there is an absence of a clear demarcation between ESs and EDSs generated by invasive alien plant species (IAPS) because of the general assumption that the kind of service depends on the context and the values imposed by people (Vaz et al. 2017). IAPS has supplied provisioning services like fuel, fodder, and food, such as the introduction of mesquite catering to the food needs in Peru (Vaz et al. 2017). Occasionally, it has also acted as a source of social cohesions between poor communities (Vaz et al. 2017), a cultural service.

The ecosystem disservices mainly include health (e.g., physical injuries in South Africa) and safety (e.g., fire potential in forest areas) (Vaz et al. 2017). Rai and Singh (2020) found negative impacts on regulating ESs, such as pest management and water treatment. Shackleton et al. (2017) identified that a decline in fodder and livestock health due to IAPS had detrimental impacts on the livelihoods of the locals. Vimercati et al. (2020) presented how different ecosystem functions of alien species can be perceived as both ESs and/or EDSs depending on the context and the beneficiary involved. For example, an alien species affecting large native predators might be an ES for livestock owners (as their livestock can be protected from predation), while it is an EDS to conservational education and eco-tourism (Vimercati et al. 2020).

The case of *Prosopis juliflora* is further elaborated in Table 3. Understanding the local population's perceived delivery of services provided by IAPS is essential to robustly capture the extent of the impact of disruption to human well-being by the aggressive spread of invasive species.

Prosopis juliflora holds significant economic and ecological value in arid and semi-arid regions worldwide, however it spread beyond its natural threshold, causing harm to ESs like tiger biodiversity in Ranthambore National Park (Dayal 2007) and regulating services like groundwater recharge and local climate regulation in the Delhi Ridge (DFW 2022b). There is no unanimous agreement or disagreement regarding the influence of *Prosopis juliflora* on ecosystems, which basically stems from variations in environmental conditions and research approaches across different studies. Three provisioning services have been considered—timber, medicinal value, and fodder; seven regulating services have been considered—local climate regulation, carbon sequestration, air quality regulation, resilience to extreme events, mediation of waste and toxic from wetlands, soil conservation, and pollination; two habitat services have been considered—habitat for biodiversity and genetic diversity; four cultural services have been considered—recreation, aesthetic appreciation, spiritual experience, and educational awareness. The ecosystem disservices that have been considered include social safety (cases of mugging, looting, etc., due to the density of *Prosopis juliflora*), human–monkey conflict, unpleasant sounds/smells/landscapes, weeds, and mosquitoes, bad visibility (due to density), network blockage (due to density), injury/harm to human health, and religious discomfort.

Table 3: Impact on ESs and EDSs Delivered by *Prosopis juliflora*

Studies	Location(s)	ES	EDS
Vaz et al. (2017)	South Africa, Ethiopia, Kenya, Portugal, Madagascar	Medicinal value (+), Food security (–), Livestock health (–), Aesthetic value (–)	Resource conflicts (+), Recreational discomfort due to thorns (+)
Rai and Singh (2020)	Mali (West Africa), Afar Region (Ethiopia)		Malarial outbreak due to parasite attraction (+)
Kumari and Khan (2018)	India	Remediation of pollutants (+)	
Mwangi and Swallow (2018)	Kenya	Food and fodder (+)	
Dayal (2007)	India	Biodiversity and prey of tigers (–)	
Shackleton et al. (2014)	India, South Africa, Malawi	Charcoal, fodder, and fuelwood (+), Water availability (–), Human and Livestock Health (–)	
Shackleton et al. (2019)	South Africa	Fuelwood (+), Fodder (+), Soil quality (+)	Health and safety (+)
		Fodder (+/–), Charcoal (+), Fuelwood (+),	Physical injuries due to thorns (+)
Laxén (2007)	Sudan	Fodder (+/–), Charcoal (+), Fuelwood (+),	Physical injuries due to thorns (+)

Note: (+): Increase in ES/EDS and (–): Decrease in ES/EDS.

2.5 Economic Valuation Methods

The economic valuation was divided into two steps. (i) In the first step, we estimate the social perception of ES and EDS delivery to respondents using photographs of native plant species and *Prosopis juliflora.* (ii) In the second step, we estimate the respondents' willingness to pay for eradicating *Prosopis juliflora* using biological suppression under various scenarios through a contingent valuation survey. Further, two additional sections captured respondents' socio-demographic background and environmental attitudes, respectively.

2.5.1 Perceived ES and EDS Supply

ESs and EDSs supply potential was captured through different perception value assignment methods for each kind of ES and EDS. Each set of questions was supported by photograph sheets of four native plant species, namely *Heens*, *wild Moringa*, *Shahtoot*, and *Makora*, that can be employed in the biological suppression of *Prosopis juliflora* and are popularly found in Asola Bhatti Wildlife Sanctuary and nearby areas. Additionally, a photograph sheet of *Prosopis juliflora* was also used. These photograph sheets were sourced from DFW (2022a).

For provisioning services, the dependency of respondents was captured using a binary choice question set (Yes/No). For regulating and supporting/habitat services and disservices, a 5-point Likert scale was adopted to capture the importance attributed to each of these services (1 = Least important to 5 = Most important). Cultural services and disservices have been found to have overlapping supply perceptions in the existing literature. Hence, a ranking score was adopted to have a delineated perception about culture services and disservices wherein the respondents were required to rank these services from 1 to 5.

2.5.2 Contingent Valuation Survey

To obtain the WTP of respondents, each respondent was asked to imagine that a nongovernmental organization (in collaboration with Asola Bhatti Wildlife Sanctuary and the Conservation Education Center (CEC), managed by Bombay Natural History Society) was collecting a contribution (in monetary terms) for a restoration project (started in 2020) that aims to recreate damaged native vegetation and/or microhabitats of the Aravallis on the lands on and near the sanctuary through the biological suppression of *Prosopis juliflora* (as explained in Table 2). The processes were thoroughly explained to the respondents so that they get an idea of the economic costs involved (both monetary and labor) to incentivize them to reveal their true preferences. For these techniques, four scenarios were presented to the respondents in terms of the threat to native plant biodiversity as shown in Table 4. Respondents were asked to reveal their maximum WTP for each of the scenario transitions, i.e., their maximum WTP in moving from A to B, B to C, and C to D.

Table 4: Scenarios in Contingent Valuation Method

Scenario A (Baseline)	Scenario B	Scenario C	Scenario D
No elimination of any plant of the invasive species (*Prosopis juliflora*) on the existing population	All plants of the invasive species (*Prosopis juliflora*) should be controlled or eradicated where they do damage to threatened/ endangered species of native plants.	All plants of invasive species (*Prosopis juliflora*) controlled or eradicated where they do damage to any native species.	All plants of invasive species (*Prosopis juliflora*) are controlled or eradicated wherever possible to prevent any kind of future damage (to other native species, economic damage to humans, etc.)

For each set of movement from one scenario to another, a set of prices (bid values) were presented to the respondents, and they were required to respond in a dichotomous way, either Yes or No (Naime et al. 2020). The bid values were decided based on the pilot survey with a minimum value of INR10 (entry fee of AB-WLS, excluding parking, camera charges, etc.). In each scenario, the set of prices started at INR10 to avoid starting point bias. The following set of prices were presented (all prices are in INR): 10, 25, 35, 45, 55, 75, 80, 90, 100, 110, 115, 125, 145, 165, 170, 180, 190, 200).

2.6 Data Analysis

Principle component analysis (PCA) was applied using Kaiser normalization criterion > 1 and Varimax rotations with 999 permutations to find an optimal solution. Further, logistic regression was used to understand the impact of the perceived supply of ES and EDS bundles on respondents' WTP for native species' restoration through biological suppression as the dependent variable takes a binary form of Yes/No. Additionally, the average (mean and median) WTP in each scenario was estimated. Median WTP has also been considered as it would give an overview of the willingness of a majority of respondents (Pearce et al., 2006, cited in Naime et al. 2020 towards eradication/control of *Prosopis juliflora* through biological suppression.

3. RESULTS AND DISCUSSION

3.1 ES and EDS Perceived Supply Bundles

PCA shows that 6 ES supply bundles and 3 EDS bundles are identified, as shown in Tables 5 and 6 The classification of ESs has been done through the identification of dominant ESs and further confirmed by component loading plots where the accumulation of a group of services indicates the association and hence, the bundle. The titles of the classifications are based on ES divisions, ES groups, and ES classes of the Common International Classification of Ecosystem Services (CICES). Similarly, the classification for EDS bundles is based on Wu, Li, and Li (2021) and Vaz et al. (2017).

Table 5: ES Bundles

Variable	Lifecycle Maintenance, Habitat and Gene Pool Protection Bundle	Regulation and Maintenance Bundle	Material and Physical Interaction Bundle	Mass Stabilization and Control of Erosion Rates Bundle	Educational Awareness Bundle	Medicinal Output Bundle
Timber	–0.032	0.130	**0.723**	0.092	0.308	–0.247
Medicinal use	–0.094	0.114	0.157	–0.029	0.236	**0.548**
Fodder	0.111	0.212	**0.828**	0.085	0.058	0.133
Local climate regulation	0.344	**0.568**	0.152	0.247	0.077	–0.322
Carbon sequestration	0.235	**0.776**	0.207	0.166	0.161	–0.073
Air purification	0.117	**0.834**	0.078	0.073	0.016	0.122
Extreme weather events regulation	0.169	**0.505**	–0.194	**0.606**	–0.101	0.082
Wastewater treatment	0.063	0.151	0.056	**0.903**	0.009	–0.056
Soil conservation	0.112	–0.062	0.198	0.53	0.210	0.019
Pollination	**0.647**	0.251	0.005	0.203	0.087	–0.184
Habitat for biodiversity (Long-term)	**0.868**	0.119	–0.083	0.053	0.074	0.058
Habitat for biodiversity (Short-term)	**0.912**	0.184	0.052	0.031	–0.006	0.056
Genetic diversity	**0.796**	0.009	0.216	0.039	–0.031	–0.150
Recreation	0.073	–0.094	**0.576**	–0.308	–0.238	0.143
Aesthetic appreciation	0.077	–0.099	0.371	–0.050	0.142	0.267
Religious and/or cultural heritage	–0.076	–0.022	–0.436	0.106	–0.646	–0.208
Educational awareness	0.031	0.102	0.016	0.064	**0.845**	–0.015

Table 6: EDS Bundles

Variable	Recreational and Religious Bundle	Connectivity Bundle	Mass Flow Bundle
Risk of forest fires or smoke	–0.0393	0.0916	0.6021
Safety Issues	–0.1119	–0.0652	–0.329
Human-monkey conflict	–0.0286	0.5768	–0.4431
Unpleasant sound/smells	0.6997	–0.1915	0.0106
Weeds/mosquitoes	0.4235	–0.2083	0.1575
Bad visibility	–0.1195	0.5571	0.1743
Network problems	–0.1288	0.6743	–0.0407
Physical injuries caused	0.5642	–0.4275	0.2336
Religious	0.6192	0.1326	–0.2278

Respondents tend to perceive a joint association in the supply of biodiversity habitat and genetic diversity. It is important to note here that it does not indicate that any species is enhancing or causing a decline in any of the services, however the supply of the two is associated. This means that people believe that utilizing ecological functions can jointly assist in delivering two or more ESs.

The lifecycle maintenance, habitat, and gene pool protection bundle has been characterized by highly positive factors related to all habitat or supporting services, including long-term and short-term habitat provision for biodiversity and pollination (regulating service), which requires biodiversity to function. The regulation and maintenance ES bundle was characterized by positive component loadings of most regulating services except for pollination. The material and physical interaction bundle was characterized by high component loadings of not only timber and fodder, but also recreational ESs, and seemed to have a positive relationship with other cultural services as well, except for religious ES. High factor loadings of soil conservation, wastewater treatment, and prevention of extreme weather events characterized mass stabilization and control of the erosion rates bundle. It was also positively related to most other regulating services while negatively associated with recreational ES. The service educational awareness itself characterized the educational awareness bundle but was negatively related to religious and/or cultural heritage ESs. The service of medicinal value itself also characterized the medicinal output bundle.

The recreational and religious EDS bundle is characterized by high component loadings of unpleasant sounds and smells in neighboring areas, and physical injuries caused due to thorns. The connectivity bundle is characterized by high component loadings of bad visibility, network issues, and human–monkey conflict due to the dense vegetation of *Prosopis juliflora*. The mass flow bundle was characterized by the risk of forest fires or smoke due to the dense and accumulated vegetation of *Prosopis juliflora*.

3.2 Economic Valuation of Eradication/Control of *Prosopis juliflora* Using Biological Suppression

Mean and median WTP for the ecological restoration of native plant species were calculated under the two techniques for the four different scenarios because median WTP will be more suitable over mean WTP from a policy perspective as it will indicate the value at which the respondents would be adequately satisfied to allow for native species' restoration under the said techniques. This is presented in Table 7.

Table 7: Mean and Median WTP across Different Scenarios (in INR)

Scenario A to B		Scenario B to C		Scenario C to D	
Mean	**Median**	**Mean**	**Median**	**Mean**	**Median**
53.58	45	63.83	75	64.17	55

There is an increasing trend in the mean WTP to move to higher scenarios with increased native species' conservation in the case of biological suppression. The median WTP increased from threatened native species restoration to any native species, but decreased if *Prosopis juliflora* was eliminated in the case of any potential economic damage. One of the locals visiting AB-WLS stated, "For places like Bhatti, I believe the dense plants that you are talking about should be replaced. Not only do they pose a risk to hikers and cyclists inside, but at times it is also detrimental to other vegetation."

3.3 Impact of ES and EDS Bundles on Respondents' WTP on Eradication/Control of *Prosopis juliflora*

Table 8 shows the logistic regression results to understand the impact of ES and EDS bundles on people's willingness to contribute towards native species' restoration under the biological suppression of *Prosopis juliflora*. Biological suppression of *Prosopis juliflora* has been considered to understand the willingness of people to remove *Prosopis juliflora* and replace those trees with fast-growing native species in an attempt to enrich the landscape with native biodiversity. Socioeconomic variables have been included as controls. The socioeconomic variables are described in the Annex.

Table 8: Regression Results in the Case of Biological Suppression

Dependent Variable: WTP (Yes/No)	Scenario A to B	Scenario B to C	Scenario C to D
Lifecycle maintenance, habitat and gene pool protection ES bundle	0.061** (0.234)	0.091* (0.198)	–0.238 (0.203)
Regulation and maintenance ES bundle	–0.230 (0.247)	–0.117 (0.218)	0.253 (0.224)
Timber	0.469 (0.441)	–0.91 (0.351)	0.233 (0.234)
Fodder	0.512 (0.321)	–0.221 (0.227)	–0.341 (0.229)
Recreation ES	0.823** (0.412)	0.724** (0.361)	0.462 (0.387)
Mass stabilization and control of erosion rates ES bundle	0.029 (0.255)	0.113 (0.236)	–0.209 (0.242)
Educational awareness ES bundle	–0.086 (0.188)	0.025 (0.160)	–0.107 (0.160)
Medicinal output ES bundle	–0.591 (0.302)	–0.603 (0.290)	0.138 (0.285)
Recreational and religious EDS bundle	0.424 (0.642)	0.966* (0.533)	–0.284 (0.512)
Gender X connectivity EDS bundle	0.049* (0.554)	0.401* (0.490)	0.223 (0.499)
Mass flow EDS bundle	1.325** (0.667)	1.358** (0.614)	–0.811 (0.688)
Age	–0.096 (0.085)	–0.006 (0.076)	–0.119 (0.102)
Gender	0.281 (0.399)	0.433 (0.346)	0.816** (0.399)
Education	–0.176* (0.105)	–0.029 (0.100)	0.044 (0.107)
Employment	0.145 (0.094)	0.166* (0.089)	0.145 (0.107)
Income	–0.042 (0.094)	0.079 (0.089)	0.043 (0.104)
Expenditure	0.022 (0.120)	–0.163 (0.107)	–0.136 (0.119)
Household size	0.105 (0.131)	0.123 (0.113)	0.023 (0.121)
Family state	0.004 (0.033)	–0.016 (0.031)	–0.008 (0.031)
Constant	0.070 (1.526)	–2.84** (1.333)	–1.314 (1.328)

***Statistically significant at 1%, ** at 5%, * at 10%.

Lifecycle maintenance, habitat, and gene pool protection ES bundle has a positive and significant impact on people's willingness to pay for the removal of *Prosopis juliflora* that impact any native plant species, indicating that people perceive that biodiversity (both short and long term) along with the associated services assisted by native plant species are affected by *Prosopis juliflora*, i.e., native plant species are overall perceived to be more suitable for providing habitat for biodiversity and preserve genetic diversity. Material and physical interaction of the ES bundle also significantly impacts the elimination of *Prosopis juliflora*, which damages any native species. However, to understand the causes of these factors, regression for all ESs was undertaken separately. Timber and fodder came out to be insignificant in the WTP for the eradication of *Prosopis juliflora*. It is important to note that a protected area was selected to control/exclude any material or biomass benefits that *Prosopis juliflora* could provide. It was found that recreational ES motivated people to promote the enrichment of native plant biodiversity and biologically suppress *Prosopis juliflora.*

Recreational and religious EDS bundle positively impacts the elimination or control of *Prosopis juliflora*, implying that people perceive *Prosopis juliflora* to be a hindrance in the leisure activities they carry out in and around AB-WLS. It is responsible for delivering disservices like unpleasant sounds or smells that cause physical injuries. It is also found that *Prosopis juliflora* seems to cause hindrance in people's religious practices or sentiments. This can be attributed to the fact that *Prosopis juliflora* supports other species like snakes that are considered to be evil or some other insects that cause nuisance to religious practices. Connectivity EDS bundles are not significant alone; however, if interacted with gender, has a positive significant impact on the control or elimination of *Prosopis juliflora* that damage any native species, indicating that the dense vegetation of the invasive species poses a significant problem in terms of visibility, network accessibility, and human–monkey conflicts for women in and around AB-WLS. The mass flow EDS bundle has a positive significant impact on the control/elimination of *Prosopis juliflora* that impacts any native species.

Results indicate that people associate the delivery of both provisional services like timber and fodder (although very limited respondents as it is a protected area) with recreational and leisure activities like hiking, cycling, etc., suggesting that many of the respondents who perceived the plant species as a source of timber were also enjoying the recreational opportunities of the forests. This is an important implication as it suggests that for these select respondents, the utility from *Prosopis juliflora* was derived from both these activities as a combined bundle, however, disregarding the fact that as a greater number of trees or plants are cut down for procurement of provisioning services like food and fodder, the recreational and leisure services would be affected even more. This becomes even more pertinent as genetic diversity and habitat for biodiversity are significant perceived services playing a major role for locals' willingness to contribute towards the biological suppression of *Prosopis juliflora*. There is a dire need for awareness regarding biodiversity conservation in such areas. The Center of Conservation (CEC) by Bombay Natural History Society has been attempting to organize programs and awareness drives at the Asola Bhatti Wildlife Sanctuary, but limited benefits have trickled down to the locals, so much so that a large section of them have either no or very little information regarding such awareness drives.

Results also convey that people perceive that a higher use of landscape or species for recreational services will also accompany a decrease in regulating services, probably because of the increased human disturbance of the area for recreation or at a larger scale for tourism purposes that can also be attributed to improper waste disposal or other human activities. Other trade-offs include those between Mass Stabilization and Control of Waste and Erosion bundles and Material and Physical Interaction bundles, indicating that people perceive that increased utilization of the landscape or species for material benefits can, in turn, pose a cost to soil health and the ability of ecosystems to prevent extreme weather events (provisioning vs. regulating services), and the trade-off between the Connectivity EDS bundle and the Recreational and Religious EDS bundle. This is an odd relationship as it suggests that people perceive that an increase in the disservices of poor visibility and network and communication blockage supplied due to the density of vegetation usually accompanies with lower recreational disservices like unpleasant sounds/smells and physical injuries and religious EDS like hurt or hindrance in religious practices. When further investigated, it was found that people who perceive that the vegetation leads to problems in connectivity problems tend to avoid those places for leisure or religious activities; hence, the disservices caused are by default decreased.

In terms of ecosystem disservices, network accessibility and visibility have continued to affect the well-being of women of these areas. Along with this, the dense canopies of *Prosopis juliflora* have made it a shelter for the monkeys that tend to escape the premises of AB-WLS and plague the well-being of the locals, especially women living in the nearby areas. This is in tandem with the research by Ganguly and Chauhan (2018). Further, the risk of forest fires that could spread and affect the livelihoods of these locals is a contributing factor towards the eradication of *Prosopis juliflora.*

4. CONCLUSION

The dominance of *Prosopis juliflora* in the Southern Ridge makes it crucial to understand the dynamics that are at play due to its invasive nature. The most impacted service by this species is biodiversity. Native restoration in protected areas can lead to a significant increase in biodiversity levels, which was agreed upon by the local population. However, the more diverse the species, the more susceptible to invasion, which makes protected areas vulnerable at the same time. Long-term monitoring and biodiversity surveillance in strictly prohibited areas like AB-WLS are required to better understand invasive species' role in native microhabitats so that it can be replicated in other landscapes and ecosystems.

This study can enable the Ridge Management Board to incorporate the perceived supply of ecosystem service bundles by the local communities assisted by the restoration of native plant species or microhabitats. Further, the choice of technique for managing the invasive species will be made considering the local communities' dependence on the invasive species for material biomass. Several agencies, including the DDA, North Delhi Municipal Corporation, South Delhi Municipal Corporation, and the Central Public Works Department (CPWD). Autonomous local bodies will be able to understand, prioritize certain techniques for elimination of invasive species based on their comparative advantages over others and develop a criteria for selection of the species assemblage to be used in restoration with minimal impact on the perceived supply and demand of ESs for the local communities and bring maximum relief from the perceived supply and demand of Ecosystem disservices. For example, *Heens (Capparis separia*) is a native species and a host plant of butterflies that is extremely drought-resistant and a binder. It is a fast-growing plant that can be utilized in the suppression of *Prosopis juliflora*. A comparative advantage would, in turn, be created if the restoration is dominant in areas where there is a synergy between the perceived demand for regulation of soil conservation (Mass stabilization and erosion and waste control bundle) and pollination or healthy habitat for biodiversity (lifecycle maintenance, habitat, and gene pool bundle) by the local communities. Moving forward, it is important to incorporate other aspects of livelihood. For example, recreational or health disservices like injuries or diseases might not be perceived by locals to cause as much nuisance if immediate and improved healthcare was accessible. Hence, there might be certain other aspects apart from provisional services like fuelwood that need to be controlled.

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ANNEX

A.1: Sociodemographic Characteristics

Category	%
Age	
Less than 15	7.78
15–20	19.44
20–25	23.89
25–30	22.78
30–35	7.22
35–40	5.56
40–45	7.78
45–50	2.22
More than 50	3.33
HH Size	%
2	1.11
3	13.33
4	38.89
5	19.44
6	15
7	6.11
8	2.78
9	1.67
10	1.11
11	0.56
Gender	No.
Female	78
Male	102
Education	%
Diploma	0.56
Graduation	42.78
Higher Secondary School	24.44
Middle School	11.67
No formal education	2.22
Post-Graduation and Above	6.67
Secondary School	10
Up to Primary School	1.67
Employment	
Casual/Daily wage worker	1.67
Freelance	0.56
Housewife	8.33
Pensioner/Retired	0.56
Regular salaried (government)	3.33
Regular salaried (private)	21.11
Self-employed/Business	24.44
Student/Researcher	29.44
Temporary/Contract Employment	4.44
Unemployed	6.11
Income (in ‘000)	
10 to 15	5.56
15–20	7.22
20–30	23.33
30–40	19.44
40–50	13.89
50–60	12.22
60–70	6.11
Less than 10	10
More than 70	2.22

A.2: Questionnaire

Good morning/afternoon/evening

My name is *Shreya Gupta,* and I would like to interview you about ___________________________The questionnaire will take approximately__ (time)__________________________________

Section 1. Socio-demographic Profile of Respondents

1. Name of the interviewee	
2. Age of the interviewee	
3. Where is your residence located?	
4. Where is your family originally from? *[please indicate the state]*	
5. What is your household size? (No. of family members)	
6. Gender	Male Female Other
7. Education	Up to primary school, formal education Secondary or *Madhyamik* Higher secondary / technical school Graduate Postgraduate and above Other: ______________________
8. Working Sector/Employment	Regular salaried (government) Regular salaried (private) Self-employed / Business Pensioner / Retired Housewife Casual / Daily Wage Worker Student / Researcher Unemployed Temporary/Contract Employment Other: ______________________
9. Income/Monthly expenditure on consumption	Less than Rs.5,000 Rs.5,000–Rs.10,000 Rs.10,000–Rs.15,000 Rs.15,000–Rs.20,000 Rs.20,000–Rs.30,000 More than Rs.30,000 Specific Income (optional)..........................

Section 2. Environmental Attitudes of Respondents

Rate your attitudes towards the environment on the basis of the following 5-point Likert scale

Environmental Empathy					
	Extremely Unimportant	**Unimportant**	**Neutral**	**Important**	**Extremely Important**
Natural Resource Conservation	1	2	3	4	5
Reducing waste levels	1	2	3	4	5
Creating and providing better living environment for future generations	1	2	3	4	5
Personally motivated concern towards the environment	1	2	3	4	5
Business and Legal					
	Extremely Unimportant	**Unimportant**	**Neutral**	**Important**	**Extremely Important**
Respecting environmental laws	1	2	3	4	5
Avoiding companies that use misleading environmental practices	1	2	3	4	5
Participation and Representation					
	Extremely Unimportant	**Unimportant**	**Neutral**	**Important**	**Extremely Important**
Often interventions using the media to combat environmental degradation	1	2	3	4	5
Supporting environmental pressure groups to combat environmental degradation through direct/indirect participation	1	2	3	4	5
Voting for political representatives because of any environmental bias	1	2	3	4	5

Section 3. ES Attributes

A. Provisioning Services:

Ecosystem services are services provided by natural resources that are directly or indirectly consumed or enjoyed by humans, thus impacting human well-being. Respond in either Yes or No to the following questions:

Provisioning Services		**Yes/No**
Agricultural products/food	Do you depend directly on *Prosopis juliflora* for food (crops, stock or fisheries)? If yes, have you experienced any irritation/ill-effects like allergies, sickness, etc. on consumption/physical proximity (during collection)?	
Timber	Do you depend on *Prosopis juliflora* for raw materials such as wood, biofuel?	
Medicinal Resources	Do you depend on populations of *Prosopis juliflora* which have medicinal value OR will you be willing to make use of plants that have medicinal potential in the future?	
Pasture and Fodder	Does it provide for pasture land and fodder for grazing?	

Regulating and Habitat/Supporting Services. Rate your preferences towards the following ES on the basis of the following 5-point Likert scale: 1 = Strongly Disagree 2 = Disagree 3 = Neutral 4 = Agree 5 = Strongly agree

Local Climate	I believe trees are important for shade and more broadly for regulating the heat produced in built-up areas	1	2	3	4	5
Carbon Sequestration	I value the reduction in greenhouse effect due to the carbon sequestration ability of trees and canopied vegetation	1	2	3	4	5
Risk of Wildfire	I fear the risk of forest fires and resulting carbon emissions due to the fire-prone vegetations of Prosopis juliflora	1	2	3	4	5
Extreme Events	I value the ability of vegetation in wetlands and other ecosystems to mediate the effect of extreme weather events such as droughts, fires, floods, etc.	1	2	3	4	5
Wastewater Treatment	I value the wetlands free of waste, toxins and other nuisances	1	2	3	4	5
Soil Conservation and Fertility	I value steep slopes with good vegetation cover as they slow the flow rainwater and protect the soil	1	2	3	4	5
Pollination	Vegetation assists in crop farming which relies on animals (insects in particular) for pollination (e.g., most fruits and vegetables)	1	2	3	4	5
Habitat for Species	I am willing to contribute (money and/or time) towards participatory activities to conserve/maintain the health of ecosystems to support a wide variety of species	1	2	3	4	5
Human–monkey conflict	I have been attacked by wild animals (llike monkeys) in and around the sanctuary.	1	2	3	4	5
Habitat's Genetic Diversity	I value typical rare cultivators or local varieties of species grown in AB-WLS	1	2	3	4	5
Air-Quality Regulation	Maintenance of air quality through filtration of dust particles	1	2	3	4	5

B. Cultural Services

Rank the following services from 1 to 4 where 1 = most preferred and 4 = least preferred

Cultural Services		Rank
Recreation	Regular use of this vegetation (forests, parks, etc.) for recreation or potential to expand nature-based recreation activities	
Aesthetic Appreciation	Appreciation of natural beauty of this area through enjoying it respectfully to taking photos or painting scenery	
Tourism	Important role in scenic spots like the Neeli Jheel and Butterfly Park for tourism	
Spiritual Experience	Practice of religions dependent on natural areas; or religious significance of particular natural areas	
Cultural Heritage	Representation of cultural heritage that conveys local culture and tradition	

Rank the following disservices in order of the nuisances caused to your well-being where 1 = Maximum nuisance value and 4 = Minimum nuisance value

Cultural Disservices		Rank
Recreation	Sounds and smells produced disrupting physical connection with nature OR Presence of weeds, pests, or mosquitoes considered unpleasant for recreation OR Unsuitable surrounding landscapes forcing preference for indoor activities	
Aesthetic Appreciation	Species perceived as disgusting and irritating OR Species or landscapes considered unpleasant Sounds and smells produced by nature disrupting physical connection with nature	
Network	Dense vegetation provoking bad visibility in traffic and communication blockage	

Section 4. Hypothetical Scenario for the Contingent Valuation

Now, I want to ask you some questions regarding your views on the ecological restoration processes being carried out at Asola Bhatti Wildlife Sanctuary.

The Department of Forests and Wildlife, Govt. of NCT of Delhi, along with the Conservation and Education Center, implemented by the Bombay Natural History Society, is currently working on a restoration program to promote eco-tourism in AB-WLS as laid out in the Management Plan 2015–16 to 2024–25. Under the plan, the Department of Forests and Wildlife intends to revive the natural ecosystem of the Aravalli range as a roadmap to restore other degraded ecosystems in the city.

The Aravalli range, the oldest range of fold mountains in India, running approx. 692 km in a southwest direction, starting in North India from Delhi and passing through southern Haryana, across the states of Rajasthan, and ending in Gujarat.

The restoration project started in 2020 and aims to recreate microhabitats or vegetation types of the Aravallis on lands at the sanctuary. These include grasslands along with *dhau* and *palash* forests. The project involves assistive regeneration. Assistive regeneration refers to the process of aiding the natural recovery and restoration of degraded or damaged ecosystems through a range of interventions designed to promote the growth and regeneration of plant and animal populations, including the use of controlled burning, soil amendments, and the introduction of native species. The invasive species that suppress natural growth have been removed, like *lantana, subabul, vilayatikikar*, and parthenium grass.

Asola Bhatti Wildlife Sanctuary is going to get a second native seed nursery along with the existing one for which a tender has been floated at an estimated cost of Rs. 2.01 crores. This new nursery, along with the existing nursery, will be used to meet the annual plantation targets of the forest department. A ‘Seed Bank’ is also being developed at the sanctuary, which collects sand and stores seeds of species that are native to the Aravalli range The Seed Bank initiative aims to bring back trees that are lost and create awareness about the disappearing species. These seeds are collected from different parts across the country like Rajasthan, Madhya Pradesh, Uttar Pradesh, Uttarakhand, and Haryana. The saplings are distributed for free to government and private institutions.

The Forest Department under the Delhi government has been carrying out projects to replace invasive *Prosopis juliflora* with indigenous species in the Asola Bhatti wildlife sanctuary (and most of the Southern Ridge). *Prosopis juliflora* is not conducive to the city's environment. Similar attempts are now being planned to remove invasive alien *subabul* and eucalyptus trees, and the weeds and waste will be dumped in the Asola Bhatti Wildlife Sanctuary.

However, there are costs involved in the restoration process, like the search costs of seeds, import costs of seeds from other states, maintenance costs of the polyhouse, greenhouse, and plantation beds, and the maintenance of cages in order to prevent wildlife disturbance.

Now, I am going to ask you to imagine that one *Prosopis juliflora* tree will be biologically suppressed and native trees/shrubs will be planted by the sanctuary of the given species. This involves the following process:

1. Procuring the seed and planting it
2. Maintaining a conducive temperature (20–28 C) in the polyhouse
3. Moving the plants to the greenhouse (stored for 10–15 days) for temperature adaptation
4. Ultimately moving the plants to the beds to allow natural growth

Baseline Scenario	**Scenario A**	**Scenario B**	**Scenario D**
No elimination of any invasive species	Damage to threatened native plants	Damage to any native plants	Any economic damage
10	10	10	10
25	25	25	25
35	35	35	35
45	45	45	45
55	55	55	55
75	75	75	75
80	80	80	80
90	90	90	90
100	100	100	100
110	110	110	110
115	115	115	115
125	125	125	125
145	145	145	145
165	165	165	165
170	170	170	170
180	180	180	180
190	190	190	190
200	200	2000	200

1 If this is done, are you willing to pay INR for restoration and plantation purposes? Yes/No

2 Please note that the money from this contribution will go directly to the wildlife sanctuary and will be used to cater for the services along with the sanctuary's wildlife conservation needs. Please think of this cost as an additional cost to all your expenses incurred in the sanctuary (including entry fee, personal vehicle, and camera costs) and to other annual expenditures. Thus, it is important that you state the **maximum amount of money** that you would pay.

[Present the respondent with the set of prices, starting from Rs.10. Circle the price in which the respondent switched from yes to no answer]

All values are in INR