Evaluating the Social and Ecological Drivers of Invasive Plant Species Abundance in Sub-tropical Community Forests of Nepal

by

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ABSTRACT

Invasive plants harm the ecological properties of natural systems, human health, and local economies. However, the negative impacts of invasive species are not always immediately visible and may be disregarded by local communities if social benefits of control efforts are not clear. In this dissertation, I use a mixed-methods approach to investigate the drivers of invasive plant distribution, potential financially feasible management techniques to control invasion, and community forest user perceptions of those techniques. In this work, I aim to incorporate the diverse perspectives of local people and increase the long-term success of invasive species control activities in socio-economically vulnerable populations.

Integrating a spatially and temporally diverse data set, I explore the social and ecological drivers of invasive plant abundance across 21 buffer zone community forests in the Western Chitwan Valley of Nepal. I evaluate to what extent forest user and collective manager activities, the legacies of historic activities, and ecological properties influence present-day invasive plant abundance. I built upon this study to identify areas with critically high levels of invasion then initiated a three-year, community-based management intervention to evaluate traditional and adaptive land management approaches to control invasive plants. I found that both approaches reduced invasive plant abundance relative to the surrounding, untreated forest. I then interviewed focus groups to investigate their perceived efficacy of the various treatment types and found that almost all forest users and managers preferred the adaptive approach over the traditional management approach. Notably, forest users cited the importance of the availability of forest resources and lack of harmful plants in the plots that had undergone this method. Understanding how forest users relate to and experience invasive plants has been relatively understudied but can influence forest user engagement in different management approaches. For this reason, I performed in-depth ethnoecological interviews to explore how forest users perceive, how they utilize, and to what extent they value invasive plants. This mixed-methods approach contributes to a more holistic understanding of the role that local people play in invasive plant management and restoration activities.

DEDICATION

To my family.

ACKNOWLEDGMENTS

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In my family we have one heirloom that holds deep meaning regarding my grandfather's immigration to the U.S. To me, it is a symbol of his humility and sacrifice. So, I would like to express gratitude for the tin cup in our rice bin that has reminded me every day to honor his legacy in my actions, my words, and my work.

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CHAPTER 1

ECOLOGICAL AND SOCIAL DRIVERS OF INVASIVE PLANT ABUNDANCE IN BUFFER ZONE COMMUNITY FORESTS WITHIN A SUBTROPICAL BIODIVERSITY HOTSPOT

ABSTRACT

Invasive plants threaten biodiversity conservation and hinder the production of natural resources, like non-timber forest products that support local livelihoods. Community forests (CFs) in the buffer zones of protected areas were created to sustainably supply resources to local people, but they are vulnerable to degradation due to intensive use. CFs operate based on community participation in forest management, which provides coordinated strategies that could suppress plant invasion. However, they also allow individual, household-based resource collection activities that could spread invasive plants, thus unintentionally counteracting management efforts. Despite the documented importance of community-based forest management for natural resource protection, the relationship between invasive species distribution, environmental factors, and human activities (individual, collective, governmental) at multiple scales. By ignoring multiple scales or focusing only on one scale, solutions to invasive species problems may be incomplete or less effective, and carefully designed interventions may fail. In this study, we ask, what is the relative importance of social and environmental factors on patterns of invasive plant abundance? We explored this social-ecological question across 21 buffer zone CFs that border Chitwan National Park, Nepal, focusing specifically on *Mikania micrantha*, an abundant and highly prolific non-native vine.

We expected uncoordinated individual activities to unintentionally promote invasive plants, whereas coordinated, collective management activities that are implemented over larger spatial scales would discourage invasion. Additionally, we expected that former governmental management practices like large-scale timber extraction and environmental factors such as proximity to rivers to be positively associated with the abundance of invasive plant species.

We found that environmental variables are stronger predictors of invasive plant abundance than social variables. For example, in every ecosystem type at least one environmental variable was significantly related to *Mikania* abundance, but individual activities were not significant in any ecosystem type. However, across all ecosystem types, individual forest user activities that altered plant community composition and productivity were positively associated with *Mikania* while other activities that were less disruptive were not. As expected, coordinated CF management activities were negatively associated with *Mikania* cover, and previous governmental management activities historically degraded the forest and contributed positively to present-day invasion dynamics. These findings suggest that (1) invasion is exacerbated by some individual resource harvesting activities but this relationship depends on the type of resource and the intensity of its extraction, (2) current CF management actions deter invasion but likely depend on the environmental context of the forest, (3) variation in historic management practices continue to promote invasion, and (4) nuisance and invasive plants species co-occur and thus could be managed in tandem.

INTRODUCTION

Tropical and subtropical forests, grasslands, and savannas support most of the world's biodiversity as well as the livelihoods of 25% of the people on Earth (FAO, 2018; Millennium Ecosystem Assessment, 2005). Globally, 1.5 billion households directly rely on non-cultivated resources from forests, which provide families as much as a third of their household earnings (Angelsen et al., 2014; FAO, 2018; Wunder, Angelsen, & Belcher, 2014). At the same time, population growth is rapidly increasing near forested protected areas and their buffer zones worldwide (Mcdonald, Kareiva, & Forman, 2008; Seto, Güneralp, & Hutyra, 2012; Spracklen, Kalamandeen, Galbraith, Gloor, & Spracklen, 2015). Increased rates of anthropogenic disturbance near protected areas degrades the resilience of forest ecosystems, threatening biodiversity as well as the long-term sustainability of resource provisioning for local communities (Johnstone et al., 2016; Laurance et al., 2012).

Community forests and buffer zones at the edges of protected areas were created to improve landscape conditions and sustainably supply resources to local people (Ishwaran, Persic, & Tri, 2008; Martino, 2001). In cases where governance and land rights are strong and population pressure is moderate, community based land management appears to be successful in reducing ecosystem degradation (DeFries, Hansen, Turner, Reid, & Liu, 2007; Gilmour, 2016; E Ostrom, 1992). For example, in Nepal, well-established and relatively large community forests have reduced land degradation and contributed to poverty alleviation (Bowler et al., 2012; Oldekop, Sims, Karna, Whittingham, & Agrawal, 2019; Pagdee, Kim, & Daugherty, 2006). However, despite local patterns of recovery in some areas, tree cover is still declining within managed community forests and protected areas globally (Laurance et al., 2012; Porter-Bolland et al., 2012). Anthropogenic disturbances alter forest productivity – sometimes conspicuously – such as with timber extraction and wildfire, but also discreetly through dispersed human activities, like non-timber resource extraction by individual forest users (Pausas & Ribeiro, 2017; Peres, Barlow, & Laurance, 2006). These less conspicuous and relatively small-scale threats are unlikely to be detected with remote sensing and thus have rarely been accounted for in ecological surveys (Laurance, 2013; Specht, Pinto, Albuquerque, Tabarelli, & Melo, 2015). Even if large-scale removal of timber resources are well managed, small-scale, chronic extraction of non-timber resources by individuals can increase the susceptibility of forests to deterioration by altering ecosystem properties and processes, including the establishment and proliferation of non-native, invasive species (Foxcroft, Pyšek, Richardson, Genovesi, & MacFadyen, 2017; Singh, 1998).

Nearly 20% of the global land area is now highly vulnerable to non-native species invasion, costing hundreds of billions of dollars per year in direct effects on cultivated crops and other provisioning services (Bradshaw et al., 2016; Paini et al., 2016; David Pimentel, Zuniga, & Morrison, 2005). The majority of biodiversity hotspots occur in developing nations, along with the greatest number of forest dependent people, but most invasive species research and detection occurs in developed countries (Early et al., 2016; Myers, Mittermeier, Mittermeier, da Fonseca, & Kent, 2000; Persha, Agrawal, & Chhatre, 2011; Sunderlin et al., 2005). Relatively few studies have examined the relationship between the spread of invasive species and disturbance-producing activities that occur daily in ecosystems of the developing world by millions of individuals who are removing non-timber forest products to support their families (Steele, Shackleton, Uma Shaanker, Ganeshaiah, & Radloff, 2015; Ticktin, 2004). Indeed, institutions designed to provision sustainable resources, like buffer zone community forests, may be most vulnerable to biological invasions (Foxcroft, Jarošík, Pyšek, Richardson, & Rouget, 2011; Wittemyer, Elsen, Bean, Burton, & Brashares, 2008). The demand for non-timber forest products is growing, but little is known about the impacts of widespread and intensive resource extraction activities by individual forest users on invasion dynamics and forest community composition (Pandey, Tripathi, & Kumar, 2016).

Invasive species problems could theoretically be managed using coordinated community-based approaches (Olson, 2009; E Ostrom, 1992; Elinor Ostrom, 2009), but few studies have explored the extent to which collective action can control these biological threats. Because invasive species tend to be prolific and have high rates of dispersal, the success of management efforts in one area is contingent upon the management efforts of neighboring stakeholders (Graham & Rogers, 2017). Some studies have suggested that social incentives to engage in collective management efforts, like participating in community forestry, can lead to greater suppression of invasive species, perhaps because collective management is inherently more responsive and less bureaucratic than top-down government programs (Epanchin-Niell & Wilen, 2015; Epanchin-Niell et al., 2010; Marshall, Coleman, Sindel, Reeve, & Berney, 2016). Nonetheless, collective management could still fail to address environmental problems in complex social and ecological landscapes (Bodin, 2017). Social and ecological forces, such as non-coordinated resource harvesting by individual households or natural disturbances, could operate antagonistically to thwart the success of invasive species management through collective action. Species invasions may be resistant to community-based management because the mechanisms for invasion may be strongly related to underlying environmental factors outside of the control of local residents (Meiners & Pickett, 2013). For example, certain forest plant communities might be susceptible to invasion because of former land-use legacies, disturbance regimes, or biophysical properties (Cabra-Rivas, Saldaña, Castro-Díez, & Gallien, 2016; Catford et al., 2012; Kuhman, Pearson, & Turner, 2010). The underlying ecological and historical management factors within a forest can alter the success of collective activities intended to reduce invasion, but the relative contribution of individual activities, collective activities, historic governmental activities, and environmental factors have not been addressed in invasive species management research.

As one of the first countries to adopt community forestry policies, Nepal is considered to be a model for successful land rehabilitation through its efforts to increase local participation in forest management (Agrawal & Gupta, 2005; Gautam & Shivakoti, 2005; Heinen & Shrestha, 2006). Given this history, Nepal's community forests are an excellent place to explore the capacity for collective action to reduce and control species invasions. Nepal is home to some of the most spectacular biophysical gradients on Earth, which support high levels of biodiversity and endemism, but it also ranks among the poorest countries globally and is threatened by the spread of damaging non-native plant species (Malik, 2013; Shrestha, 2016). Specifically, one of the most problematic invaders in the world, the vine *Mikania micrantha*, is establishing across Nepal in areas of high ecological and social concern (Lowe, Browne, Boudjelas, & De Poorter, 2000; Tiwari, Adhikari, Siwakoti, & Subedi, 2005). To date, *Mikania* has over-grown more than 25% of Chitwan National Park (CNP), a world heritage site and first national park of Nepal (Murphy *et al.*, 2013). *Mikania* overtakes the forest canopy and can kill culturally and ecologically important tree and grassland species (Siwakoti, 2008). In recent years, controlling

Mikania and other invasive plant species is of high national priority in Nepal but challenging to manage using biological control techniques (Ministry of Forests and Soil Conservation, 2017). Biological control techniques require a high degree of government oversight because they may result in undesirable and indirect effects on other organisms, they take a long time to develop, and are unlikely to be applied consistently (Funasaki, Lai, Nakahara, Beardsley, & Ota, 1988; Pearson & Callaway, 2005; Strong & Pemberton, 2000). For this reason, community-developed approaches may be the only realistic solutions towards environmental management in socioeconomically disadvantaged communities, and thus are highly important to explore. Our study explores opportunities and challenges to managing undesirable species through community-based approaches by disentangling the drivers of invasive plant proliferation across individual, collective, and historic governmental activities relative to underlying environmental factors.

In this study, we ask, what is the relative importance of individual activities by forest users, collective activities organized by community forest management committees, historic governmental activities such as timber extraction, and environmental factors on patterns of abundance of invasive plant species (Figure 1.1)? We explore this social-ecological question across 21 independently managed buffer zone community forests (CFs) that border Chitwan National Park, Nepal, a rapidly urbanizing, subtropical biodiversity hotspot with a rich history of community-based forest practices and extensive resource extraction by individuals.

We expected individual (household) activities related to resource extraction, and collective activities related to community forest management such as jungle cleaning (the traditional practice of herbaceous understory removal; (Baral & Katzensteiner, 2009), to contribute to directional changes in invasive plant species abundance by altering environmental factors such as plant species composition and plant cover. Specifically, we hypothesized that resource harvesting activities by *individuals* will be positively associated with invasive plant abundance because these non-coordinated disturbances will target the removal of desired, native plants and unintentionally promote non-native plant invasion (Figure 1.1a). In contrast, we hypothesized that *collective activities,* organized community forest management plans that are implemented across larger areas, will have both positive and negative effects on invasive plant abundance. Forest managers will employ some techniques that maintain desirable forest resources, like clearing areas of undesirable plants and constructing grass plantations, and other techniques that may improve forest conditions for plant invasion, like setting prescribed fires or flooding areas to construct wetlands (Figure 1.1b). Additionally, we expected that areas that were degraded by former top-down government actions, such as timber extraction, will be susceptible to plant species invasion as a consequence of historic land degradation that leads to reduced native species diversity, enhanced proliferation of invasive plants, and altered ecosystem resilience to invasion (Figure 1c) (Brown & Gurevitch, 2004; Johnstone et al., 2016; Kuhman et al., 2010). Finally, the complex land-use activities of this area occur within a heterogenous environment with diverse biophysical properties. Thus, we expected that some environmental factors would inhibit *Mikania* abundance (e.g. shade from intact tree canopy cover), and others would facilitate it (e.g. presence of plants that speed nutrient cycling or are avoided by people) (Figure 1.1d) (Brooker et al., 2007; Kuebbing, Nuñez, & Simberloff, 2013; Willis, Zerbe, & Kuo, 2008).

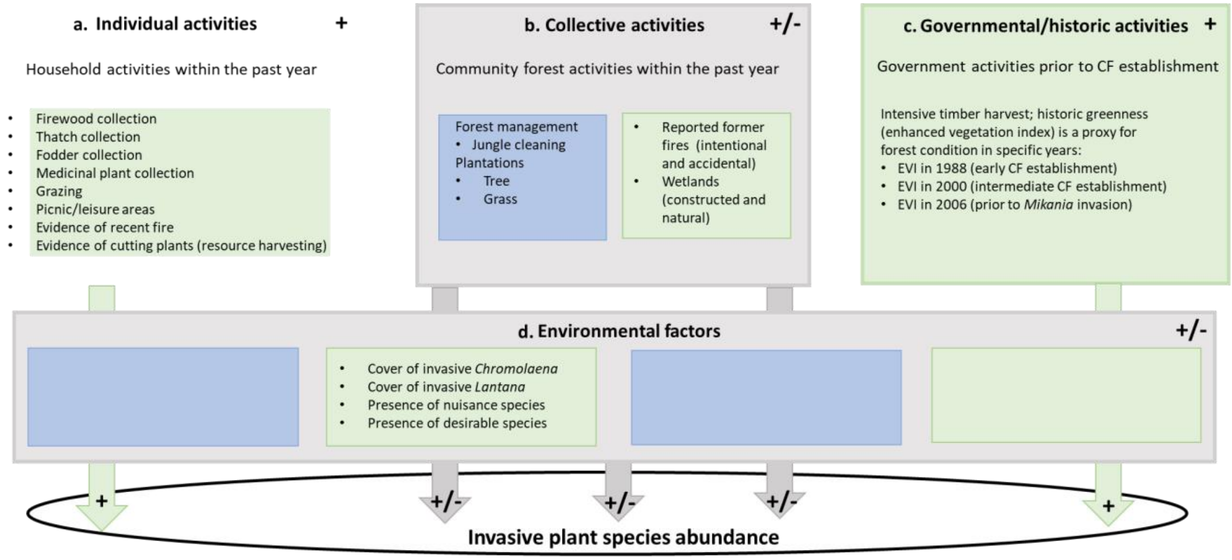

Figure 1.1. Systems diagram. Hypothesized relationships between individual, collective, and governmental (historic) forest user activities, environmental factors, and abundance of invasive plant species in Chitwan buffer zone community forests, Nepal. Social variables range in organizational scale from individual activities implemented by people, assessed through surveys at the household level (a), to collective activities reported by surveyed members of the community forest management committees (b), to historic governmental activities, approximated by EVI (enhanced vegetation Index) from specific years that reflect phases of community forest establishment prior to the invasion of the dominant non-native plant (*Mikania*) (c). Environmental factors (d) are influenced by the social factors (arrows pass through the environmental factors to imply this underlying relationship). Positive and negative signs indicate the overall hypothesized effect of each theoretical variable set (boxes) on invasive species abundance. Box color indicates the general direction of the hypothesized effect on invasive plant abundance (green boxes have a positive effect, blue boxes have a negative effect, and grey boxes imply an overall neutral effect). All 29 bulleted variables were considered as predictors of invasive species abundance in the full social-ecological model.

STUDY SITE

Ecological context. We conducted our research in 21 community forests in the buffer zone of CNP, located in the Western Chitwan Valley in the southern, lowland Terai region of Nepal (Figure 1.2). The study region is sub-tropical forest with an average annual rainfall of 250 cm and maximum temperatures ranging from 21°C to 31°C (Mishra, 1982). Rainfall predominantly occurs in the monsoon season from June to October (mean precipitation of 414 cm) while the winters are relatively dry (mean precipitation of 18 cm; (Department of Hydrology and Meteorology, 2017). Across this region, 21 CFs span three forest types and one grassland type that are associated with two highly productive soil types, including Gleyic Cambisols in riverine forests dominated by either *Bombax ceiba* or *Dalbergia sissoo*, and Eutric Greysols in non-riverine forests dominated by *Shorea robusta* (ISRIC World Soil Information). Both *Dalbergia* and *Bombax* tree species are fast growing and prefer well-drained sandy soils but *Dalbergia* forests have denser and prolonged canopy cover (Sah, Sharma, & Sehested, 2001). *Shorea robusta* forests typically have a dense understory of tall grasses collected for fodder for domesticated animals or thatch. A grassland is situated along the two riverbanks that bound the southern and northwestern edges of our study area and is composed of highly sought-after grass species that are used for thatch and fodder, including *Saccharum spp.* and *Imperata cylindrica* (also located on soils classified as Gleyic Cambisols). The boundaries of the nearby rivers, the Narayani and Rapti, change frequently due to river flooding and dynamic channeling.

Forest use and management. To explore the relative importance of individual and collective activities on the abundance of invasive species, our study design included 21 different CFs that are each managed by an elected committee, with each CF comprising hundreds of individual forest users. CF management committees oversee decisions about accessibility, resource extraction, generated income from forest products, and forest management. Though CF users and elected management committees have the right to use, manage, and protect their forests, they must also agree upon a forest management plan with the District Forest Office, a governmental organization that monitors CF programs, to ensure they are sustaining forest resources (Dahal & Chapagain, 2012; Neupane, 2003). Among our study CFs, forest management plans include organized community-based actions like ‘jungle cleaning’ to prevent over-growth of shrubs, garbage collection, and removal of nuisance plants, including invasive species (Sullivan, York, White, Hall, & Yabiku, 2017). Jungle cleaning events are coordinated by community forest managers to slash and cut herbaceous or shrubby plants and is usually applied with the intention of promoting tree growth or to remove undesirable plant species (Baral & Katzensteiner, 2009). Community forests are predominantly accessed by forest users to acquire non-timber products, like thatch for housing and construction materials, fodder for domesticated animals, and firewood. Occasionally, large groups of people picnic for leisure or cultural celebrations in select areas of the CF. In addition, some forest users graze their domesticated animals in the CF even though it is not permitted by the management committees.

CF history and land use. Forests in our study area were managed by the national government prior to the passing of the Community Forestry Act in 1993 and were heavily logged for agriculture before this date (Acharya, 2002). Much of the land inherited by communities was in poor condition due to previous intensive extraction (Nagendra, Pareeth, Sharma, Schweik, & Adhikari, 2008). Nonetheless, the decentralization of forest management, stringent timber extraction regulations, and establishment of CFs allowed forests to rebound. However, forest recovery and the process of devolving forest management from national governments to local forest user groups was not immediate. For example, in our study area, there were only three designated CFs by 2000 and the most recent of our study CFs was formalized in 2009 (Nagendra, 2002).

Ecological survey data. To quantify the potential ecological drivers and extent of invasive plant species cover, we measured ground-level biophysical variables using a transect approach across all 21 CFs from 2013-15 (Figure 1.2). Ecological surveys were delayed in some forests due to wildlife activity and disruptions from earthquakes and floods. Data from 11 CFs were collected in 2013, 7 CFs in 2014, and 3 CFs in 2015. Transects spanned the entirety of each CF and were spaced 200 m apart from one another. We established one 5 m x 10 m plot every 50 m along each transect, totaling to 2219 plots across all CFs.

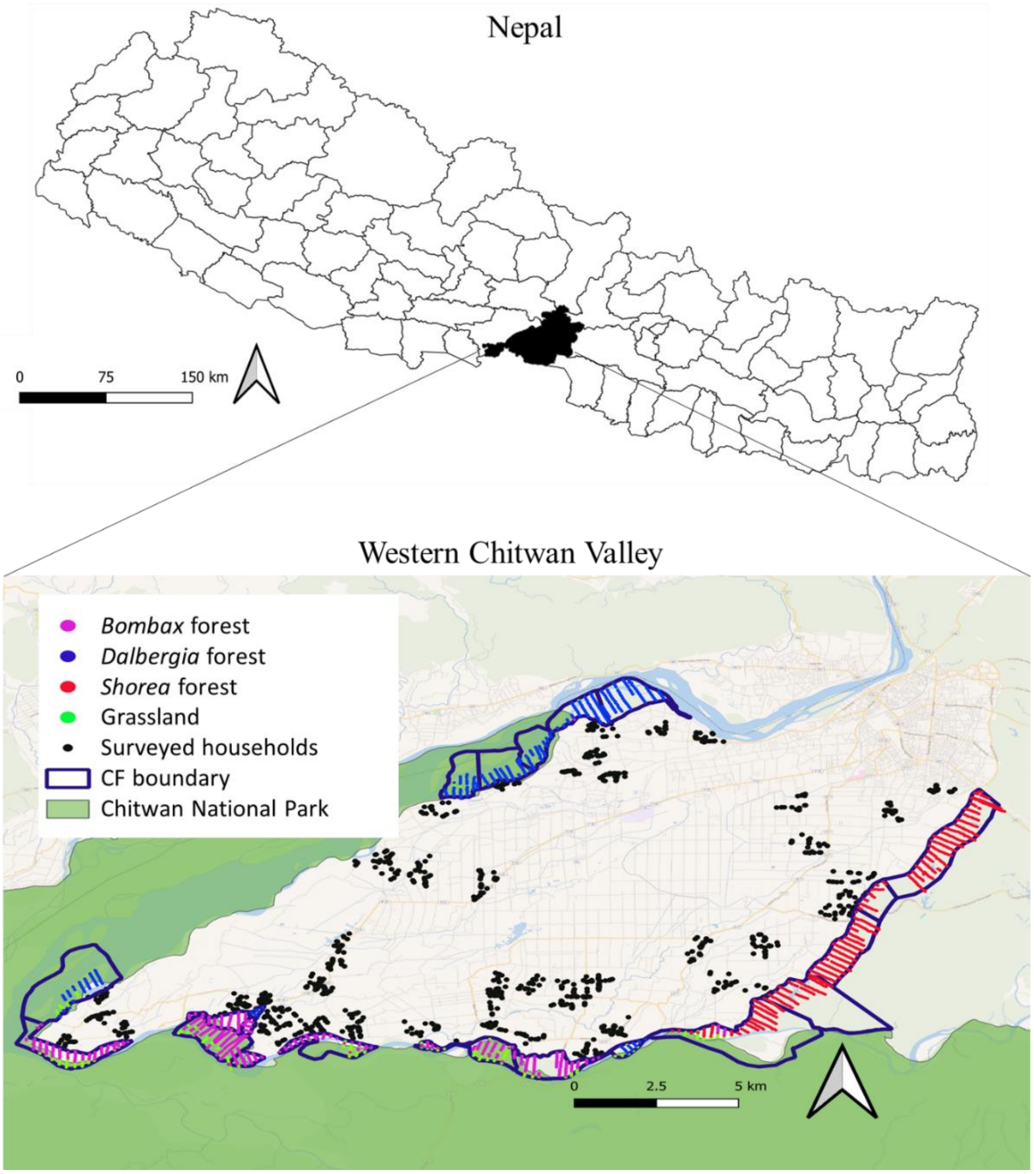

Figure 1.2. Map of Nepal (top) with Chitwan district highlighted (black). Location of study area within Western Chitwan Valley (bottom) with the location of ecological study plots (colored dots) within four ecosystem types, including Bombax-dominated mixed forest (purple), Dalbergia-dominated mixed forest (blue), Shorea robusta forest (red), and grassland (green). Black dots on the interior of the community forest boundaries are locations of households that were surveyed to identify individual forest user activities. Buffer zone community forest boundaries (dark blue line) may overlap with Chitwan National Park (dark green) near the fluctuating riverways.

In each plot, we visually surveyed the composition of dominant plant species, including three non-native invasive plant species, *Mikania micrantha*, *Chromolaena odorata,* and *Lantana camara* (hereafter referred to as *Mikania*, *Chromolaena*, and *Lantana*) using six cover classes of 0%, 0-25%, 25-50%, 50-75%, 75-100%, or 100%. We selected these three invasive species because they are considered some of the most widespread and problematic plants in our study site and in the world (Lowe et al., 2000; Tiwari et al., 2005). *Chromolaena* is an upright or sprawling shrub that grows rapidly and creates stands of monocultures that deter native seedling regeneration due to its allelopathic characteristics (Shrestha et al., 2019). *Lantana* is a thorny shrub that forms dense thickets of flammable vegetation (Sharma, Makkar, & Dawra, 1988). Though *Chromolaena* and *Lantana* are prolific, *Mikania* has the fastest growth rate, and, as an allelopathic vine, it can successfully compete for sunlight by infesting both the forest floor and canopy (Zhang, Ye, Cao, & Feng, 2004). Further, *Mikania* roots easily at its nodes and can readily establish after flood inundation in riverine forests or through unintentional transport by individual forest users who drop plant cuttings while harvesting resources (Li, Shen, Huang, Fan, & Huang, 2013; Ram, Koirala, Pradhan, & Baral 2008).

We estimated overstory tree canopy cover using a densiometer, and identified plant community composition of the overstory and understory (Lemmon, 1956). Given the spatially extensive survey area, we documented the three most abundant, mature tree species and the three most abundant understory species within each plot, excluding any of the three invasive plants already recorded. We captured the abundance of two common nuisance plant species, *Ziziphus spp.* and *Ageratum spp.,* as well as highly sought-after herbaceous species, *Saccharum spp.* and *Imperata cylindrica*.

In addition to quantitative data on plant communities, we qualitatively compiled evidence of local disturbances (presence or absence), including evidence of cutting plants that indicate resource harvesting, and evidence of recent fires within each plot. Though these local-level disturbances were collected through direct observations during the ecological survey, they are a result of individual forest user actions across the community forests, like setting fires to promote plant growth. Thus, hereafter we group these data among the individual forest user activity variables (Figure 1.1a).

Individual and collective activities survey data. To evaluate individual forest user activities and collective activities related to invasive plant species abundance, we conducted questionnaire surveys along with computer-assisted interviews separately with individual household members and elected community forest managers. The surveys were administered to respondents after pilot surveys were conducted in 2014 (Sullivan, York, An, Yabiku, & Hall, 2017) both respondent groups (individual forest users within households or community forest managers), we inquired about resource extraction activities and CF use in the last year (Appendix C and D). If respondents reported that individual members of their household or collective members of their CF had engaged in one or more resource extraction activities, then we employed a tablet-based survey approach to spatially delineate the location of forest activities on a high-resolution, digital map. Respondents who reported never visiting or extracting resources from the CFs were excluded from the tablet-based survey. All surveyed CF managers were asked to outline locations of resource extraction, forest use, and management activities in their CFs. Other surveys using a tablet-based approach have been previously tested and verified for accuracy with this study population (Yabiku, Glick, Wentz, Ghimire, & Zhao, 2017). This study was approved by Arizona State University Institutional Review Board and both CF managers and individual respondents consented per the IRB-approved protocol.

Individual forest user activities. To evaluate individual forest user activities, we selected a sample of 1261 households, of which 1094 were located within 5 km distance of a community forest. We surveyed one respondent over the age of 17 years from each household. On average, we surveyed 50 respondents from each of the 21 CFs (Appendix C). We excluded 26 households from our sample because the respondent was not a permanent resident of Nepal or they were unavailable. 1094 of the 1235 households surveyed reported performing at least one forest resource collection activity within any of the CFs in the past year, including collection of firewood, fodder, medicinal plants, and thatch; visiting the CF for leisure/recreation; and/or grazing domesticated animals. These individuals were then asked to identify the location of their forest activities by outlining polygons on a tablet-based map (Figure 1.3a). We overlaid the location of individual forest activity polygons with the ecological survey plots, then calculated the total number of overlapping activity polygons within each plot to determine the intensity of resource extraction. For any given ecological plot, values for activity variables (intensity) ranged from 0 (no activity) to 10 (maximum amount of individual forest user activity per plot, which indicates that 10 individuals selected identical locations for their forest activities). We determined the percentage of ecological plots in each ecosystem type where at least one individual reported they performed an activity. For example, 273 of the 618 plots (44%) in the *Bombax* mixed forest had at least one person identify that they extracted firewood at that location.

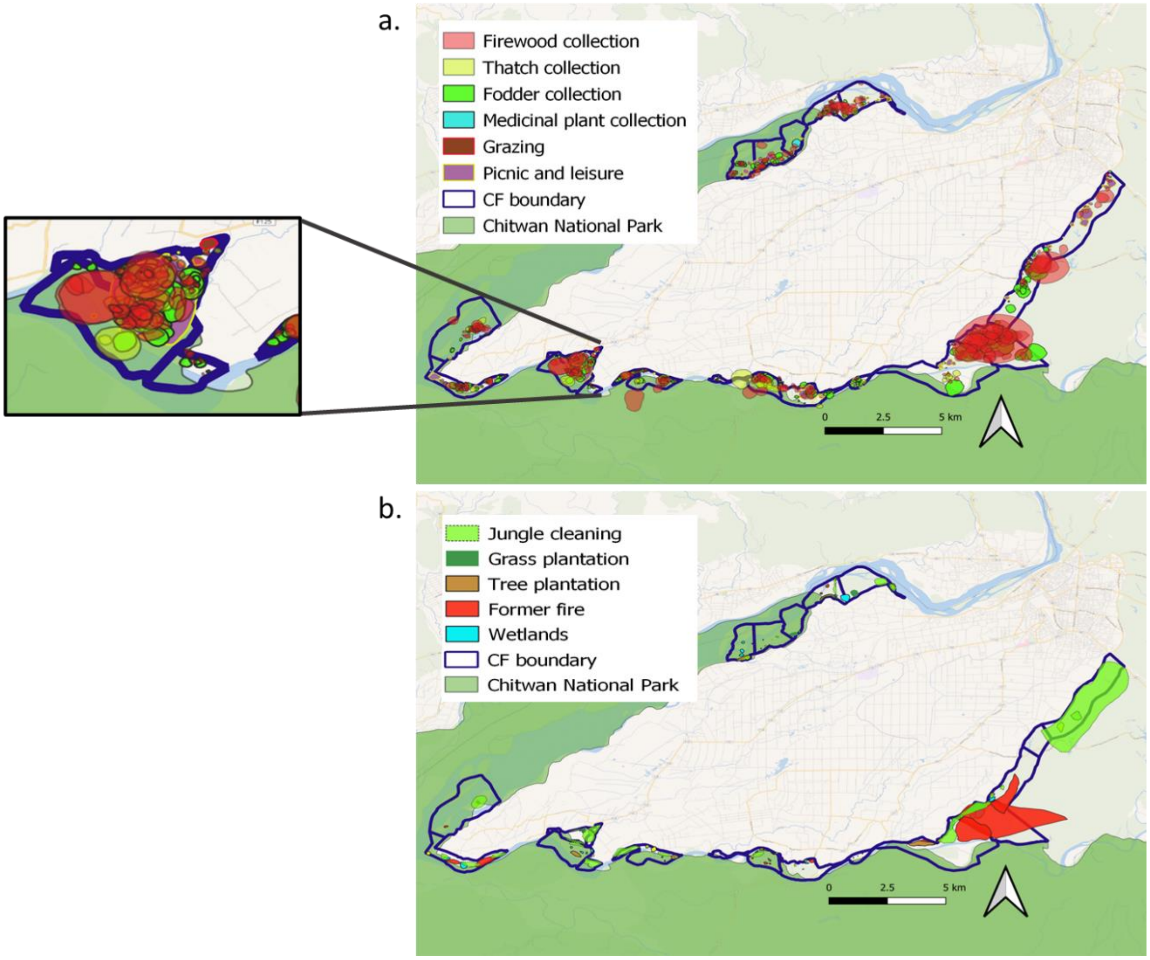

Figure 1.3. Location of individual forest user activities within community forests in the past year as reported in household surveys (a; 1094 respondents) and collective activities as identified or organized by elected community forest leaders in manager surveys (b; 21 respondents). Enlarged view (top left) shows overlapping resource collection activities outlined by individual forest users.

Collective forest management activities. To evaluate collective activities that were organized or identified by community forest managers, we administered a survey to one elected committee member from each of our 21 study CFs (Appendix D). Each respondent was asked to identify the most common management events or activities in their CF in the past year, as well as the locations of those activities on a tablet-based map (Figure 1.3b). CF management activities included grass and tree plantations, wetlands (constructed and natural), fires (intentional and accidental), and jungle cleaning. We then overlaid the locations of these collective activities across all CFs with our ecological survey plots and calculated their frequency of occurrence. Collective activity occurrence ranged from a minimum of 0 (no activity at that ecological plot) to a maximum of 1 (the CF manager reported the occurrence of an activity at that location within that CF).

Legacies of historic, governmental forest activities. To evaluate the relationship between the distribution of invasive plant species and historic legacies of government-supported timber harvest (before forest decentralization and the Community Forestry Act in 1993), we evaluated historical forest greenness using average enhanced vegetation index (EVI) from Landsat 5 TM imagery via USGS Earth Explorer. EVI is an index of greenness that ranges from -1 (no greenness) to 1 (complete greenness) and is used to detect vegetation changes overtime (Huete *et al.*, 2002). A lower EVI could indicate a loss of biomass or increased bare ground exposure potentially due to degradation, like over-grazing or over-harvesting of plants (Silleos, Alexandridis, Gitas, & Perakis, 2006). While EVI can be used to detect patterns of degradation, the index is unable to sufficiently capture shifts in plant community composition including the arrival of new species, like invasive plants, that begin to occupy degraded areas and inflate the greenness index (Karnieli *et al.*, 2013). Thus, we only use EVI as a proxy for historical degradation in years prior to *Mikania* invasion (before 2007). To represent the historical phases of key land management changes and the arrival of *Mikania* into the region, we selected three time frames: 1988-1989 (early CF establishment; 5 total CFs established by this time), 1999-2000 (15 total CFs established), and 2005-2006 (immediately prior to *Mikania* invasion; 20 total CFs established) (Dangol & Maharjan, 2012; Tiwari et al., 2005). For each of the three time periods, we compiled average EVI from September to November to avoid images obscured by clouds due to seasonal monsoons.

River delineation, road network, and elevation/slope derivation. Rivers are thought to be a source of invasive plant species like *Mikania* (Li *et al.*, 2013). The Rapti and Narayani river boundaries change annually due to flooding, which alters the vegetative and geomorphic structure of the ecosystems nearby. To assess the impact of nearby rivers on invasive plant abundance, we calculated the shortest distance from each of the ecological plots to the edge of the closest river in ArcGIS. Using Landsat imagery, we manually digitized the river boundary each year from 1988 to 2015 between the months of September and November when there was minimal cloud cover that would obscure the images. We used satellite imagery from Landsat TM (1988-1999), ETM+ (1999-2013), and OLI/TIRS (2013-2015).

Movement of invasive plant species and frequency of individual forest user activities are also facilitated by roads. Because roads are frequently disturbed, they have been considered prime habitat for invasive species (Barbosa, Wilson Fernandes, Carneiro, & Júnior, 2010; Joly et al., 2011; Mortensen, Rauschert, Nord, & Jones, 2009). Thus, we delineated all road types within and around the community forests using a road network dataset, including (from largest to smallest) highway, district road, bridge road, bridge trails, crossing ford, main trails, local trails, cart track, built-up, canal tunnel, and other non-descript roads (Humanitarian Data Exchange, 2015). We then calculated the distance from each ecological plot to the nearest road in ArcGIS. Finally, we calculated the elevation and slope of each 5 m x 10 m ecological survey plot from the ASTER GDEM downloaded from USGS Earth Explorer.

Analytical methods. The factors related to invasive plant distribution may differ based on ecosystem characteristics and the level of invasion within different plant communities (Godfree, Lepschi, & Mallinson, 2004; Peters, Yao, & Gosz, 2006; With, 2004). Previous studies have shown that *Mikania* is relatively more common in mixed, riverine forests than *Shorea robusta* forests and grasslands (Murphy *et al.*, 2013). Prior to assessing the relationship between *Mikania* and a set of predictor variables, we explored differences in *Mikania* percent cover between the four ecosystem types in our study area using a one-way ANOVA followed by a Tukey's HSD post-hoc test on *Mikania* abundance (Table 1.1). Based on these findings, and our understanding that ecosystem-scale properties influence patterns of invasion, we chose to evaluate the factors influencing *Mikania* abundance separately within the four ecosystem types in addition to holistically across all ecosystem types together.

Table 1.1. Distribution of Mikania across the four ecosystem types (N = 2219 ecological plots). The overall prevalence of *Mikania* was calculated as the total percentage of plots where at least one *Mikania* plant was present. The mean, standard deviation (SD), median, and range (minimum and maximum) of *Mikania* cover (%) are calculated for all plots invaded by Mikania. Letters in the right-most column indicate significant differences (p-value <0.05) in mean *Mikania* % cover between ecosystem types using a one-way ANOVA followed by a Tukey's HSD post-hoc test.

Ecosystem type (total number of plots)	% of plots invaded by *Mikania*	--------- *Mikania* cover (%) ---------			
		Mean (SD)	Median	Range (Min-Max)	
Bombax mixed forest (n=620)	73	29 (22.70)	25	7-87	A
Dalbergia mixed forest (n=517)	64	30 (24.49)	13	7-87	A
Shorea robusta forest (n=828)	6	18 (7.08)	13	7-68	B
Grassland (n=254)	15	11 (19.61)	13	7-88	B
All ecosystem types (N=2219)	39	28 (23.20)	13	7-88	

We explored the relationship between *Mikania* abundance and 29 predictor variables that we hypothesized to be related to invasive plant distribution (Figure 1.1) using five theoretically distinct variable sets (individual activities; collective activities; government/historic activities; environmental factors; and the full set of variables [hereafter as the 'comprehensive model']). We estimated the main effects of these variables on *Mikania* abundance within each of the four ecosystem types in our study area (*Bombax* mixed forest, *Dalbergia* mixed forest, *Shorea robusta* dominated, and grassland), as well as across all ecosystem types together (hereafter, as the 'all ecosystems'). The first model set (individual activities) assessed the main effects of non-coordinated, individual forest user activities related to *Mikania* abundance (Appendix A, Appendix C). The second model set (collective activities) tested factors related to larger-scale activities organized by CF management committees (e.g. creation/maintenance of plantations and wetlands, jungle cleaning) and other events like fires. The third model set (governmental/historic activities) tested the effect of historic, governmental legacies on *Mikania* related to intensive timber extraction. The fourth model set (environmental factors) tested the relationship between *Mikania* abundance and environmental variables exclusively. The fifth model set (the full set of variables, the comprehensive model) evaluated the overall effect of all explanatory variables on *Mikania* abundance. Each of the five model sets were evaluated within the four individual ecosystem types and across all ecosystem types for a total of 25 distinct models.

Variable selection. Prior to running the models, we removed any predictor variable that occurred in less than 5% of each ecosystem type (labeled NA in Appendix G). For example, evidence of recent fire (individual activities model) was removed from *Bombax* and *Dalbergia* mixed forest models; thatch collection (individual activities model) and evidence of flooding (environmental factors model) were infrequent in the *Shorea robusta* forest and were thus removed from the those models. The variable called 'reported former fires' (collective activities model), was removed from *Dalbergia* forest models. Additionally, data for the following variables were rare and were thus removed from all theoretical model sets in every ecosystem: grazing, medicinal plant collection, wetlands, and grass and tree plantations. All remaining predictor variables were standardized across all forest types by first subtracting the arithmetic mean and then dividing by the standard deviation using the ‘scale’ function in the ‘standardize’ package in R version 3.6.1. After standardizing the variables, we checked for collinearity by calculating variance inflation factors (VIF) to minimize inflating the standard error, but none of the variables had a VIF greater than two (Zuur, Ieno, Walker, Saveliev, & Smith, 2009).

Model selection. In each ecosystem type and across the entire study area, the distribution of *Mikania* abundance was right-skewed because of the high proportion of zeros in the dataset. To overcome this problem, zero-inflated Poisson (ZIP) and zero-inflated negative binomial (ZINB) models were compared for each ecosystem type and each of the five distinct model sets (individual, collective, and historic, governmental activities; collective activities; full set of variables). Log likelihood ratio tests were significant and Akaike’s information criterion values (AIC) for all the ZINB models were lower than ZIP models indicating that the data suffer from over-dispersion and a ZINB model should be selected over a ZIP model (Zuur *et al.*, 2009) (Appendix E). ZINB and ZIP models were constructed using the ‘glmmTMB’ and ‘pscl’ package.

We then used multi-model inferencing using the ‘dredge’ function in the ‘MuMin’ package to determine the best fit ZINB models of subsets of predictor variables for each theoretical model set in each ecosystem type. To perform multi-model inferencing, we calculated the corrected AIC values (AICc) of the ZINB models containing all possible combinations of predictor variables within each theoretical model set to produce a set of candidate models. The number of candidate models produced varied by theoretical model set and ecosystem type. For example, when evaluating the individual activities model set in the *Bombax* mixed forest, we calculated AICc for all possible combinations of individual activity variables including firewood, fodder, and thatch collection, picnic/leisure, and evidence of plant cutting. From this set of candidate models we obtained the most parsimonious model subsets by selecting only the models with an AICc less than two (Burnham & Anderson, 1998; Symonds & Moussalli, 2011) (Appendix F). Selecting competing model subsets based on information theory (AIC) helps to prevent overfitting and variance inflation in models with a high number of predictor variables (Burnham & Anderson, 1998; Mundry, 2011). In many cases, there was more than one subset model reported with an AICc <2, indicating that other models may contain different sets of predictor variables that contribute to model predictions. Thus, we applied model-averaging using the 'model.avg' function to all the subset models to provide more stable model inferences (Appendix G).

This study aims to provide practical and relevant findings regarding the relationship between ecosystem properties, forest activities (individual, collective, and governmental/historic), and invasive plant abundance both within specific ecosystem types and across the entire study area. For this reason, we constructed five comprehensive models that included only predictor variables that were considered to be important from the four theoretical models for each ecosystem type (and all ecosystem types). For example, in *Bombax* mixed forest, the individual activity of thatch collection was not identified as important in any of the individual activity model subsets with AICc < 2 (Appendix F and G) so was excluded from the comprehensive model for that ecosystem type. Similar steps were taken to construct the comprehensive model for mixed *Dalbergia* and *Shorea robusta* forests, grasslands, and all ecosystem types together (including all variables in the subset models that were considered to be important to patterns of *Mikania* abundance; Appendix F). Variables that were considered to be important in at least three (of four) ecosystem types were included in the comprehensive all-ecosystem model (Appendix B). For this reason, thatch collection (individual activities) was removed from the comprehensive model of all ecosystem types because it was only important in the grassland ecosystem. Similarly, the data for ‘reported former fires’ (collective activities) and ‘evidence of recent fires’ (individual activities) were excluded from the comprehensive models because these activities only occurred frequently in two ecosystem types (Appendix B).

RESULTS

The range of environmental properties and diversity of land use across community forests provides us with a variable landscape to gain insight into the association between social-ecological factors and invasive plant abundance. In this study, we examined the relationship between *Mikania* abundance and individual activities, land modification through collective management, historic land use, and environmental condition. We expected that individual-scale activities related to resource removal will disturb plant communities and provide pathways for plant invasion. Meanwhile, we hypothesized that larger-scale, community-based management practices will promote plant community resistance to invasion. This study area has undergone historic changes in forest management that has had lasting effects on species composition and forest productivity and, as we hypothesized, these legacy effects could influence present-day invasive plant abundance. Environmental properties, especially those that facilitate the movement of plants, will contribute to invasive plant abundance. At the same time, some environmental properties, like higher canopy cover that reduces light penetration to the forest floor, would discourage invasion. Across this study area, we found that human activities and environmental factors varied significantly, demonstrating the complex social and ecological landscapes on which plant invasions occur.

Variation in *Mikania* abundance, human activities, and environmental factors across CFs of Western Chitwan. *Mikania* invasion varied significantly across ecosystem types ($p<0.05$; Table 1.1). *Mikania* was present in 73% of *Bombax* and 64% of *Dalbergia* forest plots but was mostly absent from *Shorea robusta* forests (6% of plots) and grasslands (15% of plots). Where *Mikania* was present it was also more abundant and covered on average 30% of the plots in *Bombax* and *Dalbergia* forests compared to grasslands (11% cover) and *Shorea robusta* forest (18% cover). The mean percent cover of *Mikania* in invaded plots did not differ between riverine forests ($p = 0.18$) but was significantly lower in *Shorea robusta* forests and grasslands (Table 1.1).

Individual and collective management activities. Human activities influence environmental properties in contrasting ways, depending on the scale, type, and intensity of the activity. Forest users have access to all ecosystem types but extract different resources from each of them (e.g. firewood and fodder from forests; and thatch from grasslands). In our study area, firewood and fodder were the most extracted resource regardless of ecosystem type, ranging from 21-44% of plots for firewood, and 11-40% of plots for fodder (Appendix A, Appendix C).

Thatch collection occurred in grassland and *Bombax* forest (found in at least 15% of plots) but occurred in less than 7% of plots within *Dalbergia* and *Shorea robusta* forests (Appendix A, Appendix C). Additionally, ecosystems in this study area are not exclusively used for resource extraction. Forest users also visit CFs for their recreational value, like picnicking. Picnicking was common only in the forested areas, particularly in the *Bombax* forest (28% of the forest) but occurred in less than 3% of grasslands.

Collective activities include coordinated forest management efforts to sustain forest productivity or to promote the recovery of degraded ecosystems, usually through restoration or management activities. Similar to individual activities, larger-scale collective forest management activities were not uniformly applied across all ecosystem types. Forest management activities were most prevalent in *Shorea robusta* forests (Appendix A, Appendix C). For example, ‘jungle cleaning’ is ubiquitous across all forest types but occurs twice as often in the *Shorea robusta* forest (43% of plots) compared to both riverine forests (13-19% of plots). Further, *Shorea robusta* forests had the highest frequency of reported former fires, with at least 39% of plots having a reported fire compared to <6% of riverine forest plots and 3% of grassland plots (Appendix A, Appendix C). Overall, CF managers reported few accounts (<4%) of other coordinated management activities, like grass plantations, tree plantations, and constructed wetlands across all ecosystem types.

Governmental/historic activities. The intensity of historic forest management activities were estimated by differences in EVI in select time periods (1988, 2000, and 2006), representing the management transition from government-driven timber extraction to community-based forestry. Mean EVI across the entire study area increased from 1988 to 2006 indicating that overall plant cover increased over time. EVI was lowest in 1988 in all three forest types compared to any other time (ranging from 0.24 in *Bombax* forests to 0.39 in *Shorea robusta* forest). By 2000, all ecosystem types had higher plant cover (higher EVI) relative to 1988.

Environmental factors. Underlying environmental differences between ecosystem types are related to the frequency of individual and collective activities. For example, evidence of flooding was highly variable across the forest types (4-39% of plots) but was found in 96% of the grassland plots. Riverine forest plots were located at lower elevations, and closer to rivers (on average, within 400-500 m of the nearest river), compared to *Shorea robusta* forest plots (mean distance to river >2600 m). However, variability in slope (0-26 degrees) and elevation (120-222 m) was relatively low across all four ecosystem types. *Shorea robusta* forest plots were the closest to roadways, within 142 m on average, whereas riverine forests and grasslands were at least 200 m away from the nearest road.

Canopy cover, measured as the percentage of overstory tree cover, was relatively similar across all forest types (51-67% mean cover) but was minimal in the grasslands (<1% cover). *Shorea robusta* forests are typically dominated by a single tree species and grasslands have few occurrences of trees, so mean overstory richness was lower in these ecosystem types compared to riverine forests (average of 0.04 overstory tree species in grasslands, 1.30 in *Shorea robusta* forests, and 2.27-2.52 in riverine forests). Meanwhile, understory species richness was relatively similar across the ecosystem types and ranged from 3.27 in grasslands to 3.90 in *Shorea robusta* forests.

Besides *Mikania*, two other invasive plants, *Chromolaena* and *Lantana*, occurred in the study area but were unevenly distributed across ecosystem types. Though *Mikania* is the most widespread invader across the study site, *Chromolaena* is the most prolific invasive plant in *Shorea robusta* forests (present in 68% of plots with a mean cover of 13%) and is common in *Bombax* forests (present in 65% of plots with a mean cover of 10%). *Chromolaena* occurs in 15-26% of grassland and *Dalbergia* forest plots but occupies less than 3% of cover within invaded plots. *Lantana* was present in 4-22% of forest plots, but *Lantana* makes up less than 4% of the cover in any invaded plot. We also identified the presence of nuisance plants in the genera *Ziziphus spp.* and *Ageratum spp* because these taxa have harmful properties like thorns, chemical irritants (poisonous to livestock), or physically impede resource collection (dense foliage or impenetrable structure). Nuisance plants occurred primarily in *Bombax* forest (62% of plots) and are present in at least 29% of grassland and *Dalbergia* forest, but only 1% of *Shorea robusta* forest (Appendix A, Appendix C). Though people might be deterred by the presence of nuisance species, they may also be inclined to visit the forest if there is an abundance of desirable plant species, like fodder or thatch plants. Desirable species (the grasses *Saccharum spp.* and *Imperata cylindrica*) range from 32% of plots in *Dalbergia* forest to 88% of plots in *Shorea robusta* forest but occur in nearly all plots (97% of plots) in grasslands.

Individual activities. We hypothesized that all individual activities would contribute to *Mikania* abundance by disturbing plant communities and unintentionally promoting conditions for invasion. In the comprehensive model (all human and environmental variables together) across all ecosystem types, firewood collection, evidence of plant cutting, and areas of picnicking were all significantly and negatively associated with *Mikania* abundance, and fodder collection was positively associated with *Mikania* (Appendix B). However, none of these variables were strongly related to *Mikania* abundance (at alpha = 0.05) in any ecosystem type alone. Further examination of the individual activity model subsets (Appendix F), shows that firewood collection is significantly (and positively) related to *Mikania* abundance only in *Bombax* forests; and fodder collection, plant cutting, and picnicking were insignificant predictors in any ecosystem type. Thatch collection, the least prevalent resource collection activity (occurs in 9% of the study area), was not a significant predictor of *Mikania* abundance in any ecosystem type and was not selected for inclusion in the comprehensive model (Appendix B). Though not an extractive activity, individual fires are often applied to promote growth of grass and thatch species for collection, but evidence of fire was also not related to invasive plant abundance. Together, these results suggest that individual activities are not as conclusively linked to invasive plant cover as much as other theoretical variable sets (collective, governmental, and environmental variables) in our study region.

Collective activities. Unlike individual activities, coordinated community-based management activities are often applied to improve forest condition or alter forest properties to increase resource availability. We hypothesized that the relationship between collective activities and *Mikania* abundance would depend upon the type of activity employed. In particular, management activities aimed at improving forest condition, like jungle cleaning, would be negatively related to *Mikania* while activities intended to alter plant communities and ecological properties on a larger scale, like prescribed fires and wetland construction, would be positively related. While we were able to assess the impact of management activities like jungle cleaning and larger scale events like former fires, restoration activities (constructing plantations and wetlands) were too infrequent to evaluate as predictors of *Mikania* abundance within the entire our study area.

Nonetheless, in the comprehensive model, collectively organized jungle cleaning activities were significantly and negatively correlated with *Mikania* abundance, but only in *Bombax* forests (p=0.03) where 19% of plots had undergone jungle cleaning in the past year. Jungle cleaning variable was not significantly related to *Mikania* abundance in any other ecosystem type, even though it was reported in 13-43% of all other forest plots. Similarly, reported former fire was significantly related to *Mikania* abundance only in *Bombax* forests, where the relationship was negative. Inspection of the theoretical subset models (Appendix G) also shows significant and negative relationships between *Mikania* abundance and both jungle cleaning and reported former fire across all ecosystems, and a negative relationship between *Mikania* and former fire in *Shorea robusta* forests.

Governmental/historic activities. Historic, governmental activities, like intense timber extraction, shape present day invasion across all ecosystem types. We hypothesized that areas formerly degraded by top-down government actions, such as intense timber extraction, will be susceptible to plant species invasion. In Nepal, the historic loss of forest cover and subsequent reforestation has been attributed to the institutional shift in forest management from centralized (top-down) to community-based (bottom-up) control (Nagendra, Karmacharya, & Karna, 2005). A study by Panta, Kim, and Joshi (2008), found that Chitwan forests decreased in productivity in 1989 and 2001 compared to 1976 (prior to intensive deforestation). However, as more forests were coming under the control of community forest managers, after the Community Forestry Act of 1993 passed, forest cover began to increase in surrounding forests in Nepal (Gautam, Webb, & Eiumnoh, 2002). Similarly, across the entire study area, we found a linearly increasing trend in forest productivity, as approximated by EVI, as more forests transitioned to CF management from 1988 to 2006 (Appendix A, Appendix C). Across all ecosystem types, areas that were historically degraded (as inferred by a lower EVI in 1988 and 2000; (Panta et al., 2008) were more likely to have higher *Mikania* cover in the present (2015) though this was only significant in the year 1988 (alpha < 0.01) but not in 2000 (alpha < 0.10) (Appendix B). However, by 2006, when 20 of the 21 forests had come under CF management and were considered to be increasing in forest cover relative to their former impoverished condition, the pattern reversed, where forests with a higher EVI were likely to also have higher *Mikania* cover in the present. When ecosystems were modeled separately, results show that historic forest cover in 2006 was significantly and positively correlated with *Mikania* abundance in the *Bombax* forests but not the other ecosystems (Appendix B).

Environmental factors. We hypothesized that diverse biophysical properties across the study areas would both inhibit and facilitate invasion. Some environmental factors, like higher canopy cover and species richness, would increase resistance to *Mikania* invasion while the presence of other invasive or nuisance plants and proximity to pathways for invasion (roads and rivers) would be positively associated with *Mikania* abundance. In contrast to individual and collective human activities, several environmental variables are significant predictors of *Mikania* abundance in all ecosystems across the study area (Appendix B). Furthermore, environmental factors are the *only* significant predictors in the comprehensive model within *Dalbergia* mixed forest and grasslands, where human activity variables (including historic EVI) were unrelated to present-day *Mikania* cover. Of the 13 environmental variables assessed, 12 variables were consistently selected (Appendix F) and included in the all-ecosystem comprehensive model

(Appendix B), and 7 of these 12 environmental variables were significantly associated with *Mikania* cover at the $p \leq 0.01$ level.

Environmental variables related to plant species richness and abundance (excluding invasive plants) are among the most important factors that contribute to an ecosystem's susceptibility to invasion. Contrary to our expectations, plant species richness, both in the understory and overstory, was positively associated with *Mikania* cover across all ecosystem types, and particularly in mixed *Dalbergia* forests. However, in support of our expectations, other invasive plants species (e.g. *Lantana* or *Chromolaena*) are significantly related to *Mikania* cover in ecosystem types where *Mikania* invasion is common. Specifically, in both mixed forest types, where *Chromolaena* is present but not the dominant invader, *Chromolaena* and *Mikania* were likely to co-occur and both be abundant ($p < 0.001$). In contrast, in *Shorea robusta* forest where *Chromolaena* is the dominant invader, *Mikania* is less likely to co-occur. Finally, as expected across all ecosystems, the abundance of desirable plant species was strongly and negatively related to *Mikania* cover, and the abundance of nuisance plant species was strongly and positively related to *Mikania* cover. These patterns were most clear in the mixed riverine forests where *Mikania* invasion is severe (Appendix B; Appendix G).

Despite the importance of light availability for *Mikania* growth, overstory canopy cover was not associated with *Mikania* abundance. Further, we expected fallen trees to reduce the overall canopy cover and allow light to penetrate the forest floor and stimulate the growth of *Mikania* in these areas. However, evidence of fallen trees had no significant relationship with *Mikania* abundance.

Several biophysical and geographic variables were considered to be statistically important to *Mikania* cover (Appendix G) and were thus included in the comprehensive model of all ecosystem types. Given that roads and trails are known vectors for invasive plant transport, it was surprising to find that nearness to roads was not selected in the comprehensive model across all ecosystem types (Appendix F), although there was little variability in the distance to road variable across all plots (Appendix A, Appendix C). As expected, elevation and distance to the river were negatively correlated with *Mikania* cover when considering all ecosystem types together. Though we would expect areas near rivers to flood more frequently and promote *Mikania* establishment, direct evidence of flooding in riverine forests was negatively related to *Mikania* abundance.

DISCUSSION

Our research shows that some social variables are significant predictors of invasive plant abundance, but it is more often the environmental variables that shape the current pattern of invasion. We observed significant relationships between *Mikania* abundance and individual forest user activities in most ecosystem types but found that *Mikania* cover depends upon the timing and type of non-timber resource extraction. In addition, collectively organized activities, like jungle cleaning, had a strong influence on *Mikania* cover when assessed within specific ecosystem types, but were less influential drivers when assessed across the entire study area. Though current management actions impact *Mikania* cover, historic, governmental actions play an important role in determining *Mikania* invasion in the present day. Overall, environmental variables, especially those related to species richness and composition, are the primary predictors of invasion.

Small-scale resource extraction conducted by individual forest users may not always lead to increased invasibility as has been suggested in some studies (Foxcroft et al., 2017; Singh, 1998). Rather, community forest susceptibility to invasion may depend on resource harvesting pressure and the type of resource being extracted. We assume that resource removal is a driver of *Mikania* abundance for two reasons, 1)*Mikania* is not a primary fodder resource, so it is unlikely that forest users are intentionally accessing areas where *Mikania* is more abundant to collect fodder, and 2) *Mikania* is less likely to co-occur with grass species that could be used as fodder, so the relationship between *Mikania* abundance and resource removal is more likely a result of disturbance caused by extraction. Further, we should consider the timing of the activity of fodder removal both through direct observation (plant cutting) and reported locations (household fodder collection). Direct resource harvesting (plant cutting) is only able to be detected on a shorter temporal scale and was observed at the same time of the ecological data collection (when *Mikania* cover was measured). Thus, forest users cut plants in areas that have less *Mikania* in that moment. Meanwhile, the variable, fodder collection, was identified within one year of the activity occurring and captures the intensity (frequency of occurrence) of collection. Therefore, the positive relationship between *Mikania* abundance and fodder collection implies that *Mikania* becomes more abundant in areas that have experienced frequent disturbance caused by previous fodder removal.

Our findings suggest that there may be a difference between widespread activities, like firewood collection, and intensive, disturbance-producing activities, like fodder collection, on plant invasion success. For example, intensive resource extraction (i.e. removal of fodder) contributes positively to *Mikania* abundance. Whereas, widespread activities (i.e. firewood removal) are associated with lower invasive plant abundance. This finding could be due to the type of resource being removed. Only dead or downed tree branches and woody material can be collected for firewood, which differs from the more destructive extraction of live plant biomass for fodder collection. Thus, the process of removing fodder from the forest is more disruptive to the surrounding vegetation than firewood removal in this system (Shahabuddin & Prasad, 2004). Perhaps, the chronic extraction of resources is more likely to encourage the spread of seeds or increase disturbed areas that promote invasive plant establishment (Foxcroft, Pyšek, Richardson, & Genovesi, 2013; Ribeiro, Arroyo-Rodríguez, Santos, Tabarelli, & Leal, 2015). In other studies, firewood removal is a major source of anthropogenic forest degradation, perhaps because the extraction pressure for this resource is higher (Specht *et al.*, 2015). But in the context of this study area, fodder removal is the chronic anthropogenic disturbance and is more likely to be associated with invasive plant abundance.

To our knowledge, our study is the first to incorporate forest user-reported locations of individual-level resource harvesting activities across community forests complemented by direct plot level observations of resource harvesting. Though we have shown that individual forest user activities impact invasive plant abundance, these activities have rarely been accounted for in ecological or remote sensing surveys because they are relatively small-scale and are more difficult to detect (Laurance, 2013; Specht *et al.*, 2015). We assessed both plot-level identified locations of direct resource harvesting (determined by the researcher) and individual forest-user reported locations of resource harvesting and found that both measurement types were strong predictors of *Mikania* cover. However, both types of measurements offer different temporal and spatial scales of human-caused disturbance. Plot level assessments only detected single observable moments of resource removal. Whereas, forest-user surveys identify both the spread (i.e. the spatial distribution) and intensity (i.e. the frequency of overlap) of resource extraction over time. As a result, forest-user surveys are better able to capture the spatial and temporal pattern of resource extraction in forests. For example, including forest-user detected fodder and firewood collection improved the predictive capability of the individual activity models, suggesting that they are also necessary to understand invasive plant abundance. These findings are important, not only to understanding the drivers of invasive plants proliferation, but also in evaluating alternative approaches to detecting the intensity and spread of non-timber forest product collection in forest understories.

Collective activities, like community forest management, could theoretically deter invasion by applying coordinated community-based approaches that control biological threats. But the effects of the prominent forest management activity, jungle cleaning, on invasive plant abundance had not been previously assessed in any other study. Further, we were not sure to what extent this approach was being implemented across community forests. We found that jungle cleaning was applied in all forest types, but was concentrated heavily in *Shorea robusta* forests, perhaps because *Shorea robusta* forests support one of the most culturally and economically valuable tree species in Nepal (Timilsina, Ross, & Heinen, 2007). Though jungle cleaning had an overall negative influence on *Mikania* across the study area, the effect was not significant within individual ecosystem types, except *Bombax* forest. This finding implies that forest management activities could have different environmental effects that depend upon the social and ecological context of the study area. For example, jungle cleaning could unintentionally promote vegetative re-sprouters, like *Mikania* and many other invasive plants, in forests where invasive plant abundance has reached a higher threshold (Panetta & Gooden, 2017). While our study found that jungle cleaning was not significantly related to invasion across the entire study area, further studies should be conducted to determine species specific responses and management motivations for employing this collective activity. An expanded study would be especially salient now that Nepal has prioritized invasive species removal as a conservation goal (Ministry of Forests and Soil Conservation, 2017).

Not all invasive species management challenges can be solved by community-based approaches alone. The mechanisms for invasion may be related to historic or underlying environmental factors (Meiners & Pickett, 2013). We found that governmental, historic activities were positively correlated with present day susceptibility to invasion. Perhaps, because the forests were intensively harvested for timber prior to the establishment of the CFs (Nagendra, 2002). However, by 2006, when most forests in our study area were being managed collectively, the trend was reversed, suggesting that areas with increased forest productivity were related to higher *Mikania* abundance in the present. We suppose that once *Mikania* was introduced to this study area in 2007, it effectively out-competed plant communities in historically degraded sites (1989 and 2000) and, by 2006, when forests had generally regenerated, *Mikania* capitalized on resource availability and improved forest conditions. Other studies have found that land use legacies can have a profound and lasting impact on ecosystem properties that can encourage the establishment of invasive plants (Kuhman *et al.*, 2010; Vilà & Ibáñez, 2011). Further, frequent forest users and visitors can contribute to the perpetual introduction of new, potentially invasive species and promote invasion through continued disturbance (Lonsdale, 1999). Consequently, land managers should consider historic and current land use activities, especially intensive land change activities, that could impede invasive species management goals.

Despite the direct effect of social factors on invasive plant transport and management, the abiotic and biotic conditions within the environment are the primary filter that determine invasive species establishment and proliferation (Hobbs & Norton, 2004). The presence of other invasive plants indicates that there may be other factors that make the ecosystem type more vulnerable to invasion. The presence of nuisance species and other invasive plants in mixed forests are strong predictors of *Mikania* abundance. Similarly, other studies have shown that invasive plants tend to co-occur, especially in the initial phases of invasion (Kuebbing, Classen, & Simberloff, 2014). However, in later stages of invasion, competitively superior invasive plants, are more likely to suppress the growth of co-occurring invaders, as was the case with *Chromolaena* and *Mikania* abundance in *Shorea robusta* forests.

As the demand for non-timber forest products grows, it is important to assess how invasive plant species influence resource availability, especially in communities that are highly dependent on forests for their livelihood needs (Pandey *et al.*, 2016). The complexity of our findings suggests that there may not be one single driving mechanism for invasion. Though excessive resource extraction could increase invasive plant abundance, we found that, overall, these social variables are less important to invasion than the underlying ecological factors. In order to effectively manage invasive species, proactive control efforts that focus predominantly on altering the environmental and social factors that promote invasion should be initiated. Because of the nature of invasive species spread, management approaches should be adopted collectively across all forest types to prevent further proliferation.

Overall, our study is one of the first to systematically evaluate how different predictor variables from varying institutional scales (individual, collective, and governmental) influence the distribution of invasive plants. Further, this study is the first to use social surveys as a means of capturing the direct, spatial location of forest resource extraction and management activities rather than relying only on proxy variables that are correlated with resource use (Albuquerque *et al.*, 2018). For this reason, our study accurately reflects the consequences of social variables on invasive plant abundance. In addition, this study offers a holistic approach to understanding susceptibility to invasion across multiple heterogeneously managed ecosystem types. The social and ecological survey approach presented here could be applied to future studies and could explore a wider range of possible drivers, like abundance or seasonality of resource extraction, that might contribute to invasion.

ACKNOWLEDGEMENTS

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CHAPTER 2

ASSESSING A LOW-TECHNOLOGY AND LOW-COST INTERVENTION TO CONTROL INVASIVE PLANTS IN THE COMMUNITY FORESTS OF CHITWAN, NEPAL

ABSTRACT

In community forests of Nepal, forest user livelihoods, ecological properties, and ecosystem processes are threatened by some of the world's worst invasive plant species, but comprehensive and affordable invasive plant management solutions are lacking. Resource users and managers in community forests have engaged in traditional management activities, but the ecological effect is not documented and could unintentionally promote certain invasive plants. We tested the effectiveness of low-cost, low-technology mechanical techniques to help communities combat the spread of invading plants. We tested these hypotheses using a community-based participatory approach in five community forests (CF) located in the buffer zone of Chitwan National Park. Specifically, we explored the effectiveness of a mechanical control technique that is widely used by forest users in this region (traditional "jungle cleaning" method; cutting all herbaceous vegetation and discarding on the ground) and compared it to a modified mechanical approach intended to decrease inadvertent invasive species dispersal (bag-and-bury method; uprooting, bagging, and burying only invasive plants and allowing all other vegetation to remain). We measured invasive species cover and biomass after three years of mechanical treatments with and without prescribed fire, which is a common occurrence in CFs in this region.

Cover of the dominant invasive plant, *Mikania micrantha*, was significantly lower in both the modified (bag-and-bury) and traditional (jungle cleaning) mechanical treatments when compared to the pre-treatment plots. Furthermore, both mechanical treatments reduced invasive plant biomass and increased species richness of native plants compared to untreated, reference plots in the surrounding forest. However, when considering the efficacy of the treatment over time (after multiple treatment applications) the modified method reduced total invasive plant cover, but the traditional method did not become more effective with more treatment applications. This evidence suggests that neither the traditional and modified approaches have deleterious, non-target effects on native plant community composition and can effectively mitigate cover and biomass of some invasive plants. However, the modified approach is most likely to be beneficial for communities over the long term due to repeated removal of undesirable plants during seasons of intensive forest resource use by community members. This evidence suggests that the low-cost and low-technology management approaches, including both traditional or modified mechanical treatments, can mitigate the effects of some invasive plants in the buffer zones of protected areas of Nepal. By assessing the ecological efficacy of locally employed and financially feasible land management approaches we address both the social and ecological dimensions of invasive species management to find holistic solutions towards invasive plant management in working landscapes.

INTRODUCTION

Invasive species negatively influence agricultural and forest productivity, and the natural systems that are important to people's livelihoods (DeFries et al., 2007; Reid, Morin, Downey, French, & Virtue, 2009). The deleterious effect of invasive species on natural resource availability is especially salient in developing countries, where access to natural resources benefit local economies and alleviate poverty (Nuñez & Pauchard, 2010; Sunderlin et al., 2005). Despite the global extent of species invasion, invasive plant management research and applications have been overwhelmingly limited to developed countries, with the majority of invasive species research occurring in North America alone (Lindemann-Matthies, 2016; Pysek et al., 2008; Selge, Fischer, & van der Wal, 2011; Sharp, Larson, & Green, 2011; Verbrugge, Van den Born, & Lenders, 2013). However, invasive plant control practices that were created to suit the management needs of developed countries may not be financially feasible or socially acceptable in developing nations, or they can have non-target effects on native and desirable plant species that are critical to sustaining local livelihoods (Dickie et al., 2014; Suckling & Sforza, 2014; van Wilgen, Moran, & Hoffmann, 2013; Zarnetske, Seabloom, & Hacker, 2010). Thus, management practices that are inaccessible to developing nations, which often have the lowest capacity to respond to invasion, further divide and limit our knowledge of the human dimensions of species invasions in communities with a strong human-environmental link (Early et al., 2016).

Historically, invasive plant management research has neglected the social complexities of working landscapes where invasive species thrive and have rarely assessed community-based practices towards management (Beever et al., 2019; Dangles et al., 2010). Yet, other studies have shown that engaging community users to participate in management actions can lead to enhanced monitoring of biodiversity and more robust conservation and natural resources management programs with relatively few operational costs or external equipment or technologies needed to conduct them (Ballard & Belsky, 2010; Berkes, 2007; Fernandez-

Gimenez, Ballard, & Sturtevant, 2008; Okumu & Muchapondwa, 2020). In the same vein, invasive plant management programs that do not engage local resource users can fail if management programs are socially inappropriate or if there is disconnect between the management decision-making and natural resource user engagement (Crowley, Hinchliffe, & McDonald, 2017a; Estévez, Anderson, Pizarro, & Burgman, 2015; Novoa et al., 2018; Shackleton, Larson, Novoa, Richardson, & Kull, 2019). Thus, social-ecological studies on community-based participatory land management strategies are more likely to result in practical management solutions but have been relatively understudied in the context of species invasions (Dangles et al., 2010).

Restoration of invaded systems over the long term will require both ecologically suitable and culturally/financially feasible management solutions. In the absence of centralized governmental interventions, forest management activities, like those required for effective invasive species management, will fall to local users (to implement, either individually or collectively (Graham et al., 2019; Okumu & Muchapondwa, 2020). However, in the current literature, it is unclear how local resource users engage in invasive species control activities and how those management activities influence ecological properties (García-Llorente et al., 2011; Niemiec, Ardoin, Wharton, & Asner, 2016; Sharp et al., 2011). Understanding the ecological effects of collective management actions in invaded social-ecological systems is relevant because community-based approaches to invasive species management are potentially more successful than top-down government approaches (Graham & Rogers, 2017; Graham et al., 2019; Marshall et al., 2016). Further, studies have shown that resource users and managers tend to be more satisfied with invasive plant management activities that are cost-efficient and familiar to them (Kelley, Fernandez-Gimenez, & Brown, 2013; Ravnborg, 2004). Thus, addressing species invasion by including the diverse practices of local communities is critical for the successful management of invasive species (García-Llorente, Martín-López, González, Alcorlo, & Montes, 2008). Management efforts that modify existing approaches to better suit ecological challenges, and sustain resources relied upon for local livelihoods, are more likely to result in socially acceptable management solutions.

Diverse resource users interact with and rely upon rural forested land areas, particularly in common property areas like community forests (CFs) which were established to conserve forest resources through local participation in management (Pagdee et al., 2006). Nepal, a developing country with a long history of community forest management and a relatively recent history of plant invasion, provides a rich ecological context and diverse social landscape in which to explore the effects of different community-based practices on invasive plant species (Nagendra, 2002; Tiwari et al., 2005). As a signatory to the Convention on Biological Diversity, Nepal is required to find solutions for invasive species by 2020 (Khanal, 2014; Shrestha, 2016). However, achieving this goal might ultimately fall on community forest user groups who, as stated in the Forest Act of 1993, have the responsibility to manage and protect their designated national forest land (Acharya, 2002). As a result, land managers have employed socially and economically feasible management approaches to improve ecosystem services in their forests, often leveraging community forest users and members to locally organize forest management activities (Sullivan, York, An, et al., 2017). Management interventions are commonly used by communities to maintain a system within a desirable condition or improve it (Hobbs, Hallett, Ehrlich, & Mooney, 2011). To date, few studies have investigated the impacts of bottom-up, community-based management interventions on the vegetation composition or productivity, especially as it relates to novel species invasions (Fernandez-Gimenez et al., 2008; Pearson, Ortega, Runyon, & Butler, 2016; Reid et al., 2009).

Social-ecological communities with long-standing local governance structures could be better suited towards active and long-term management of invasive plants than top-down management approaches. However, there is a general lack of knowledge regarding local-level invasive plant control methods, especially outside of agricultural systems. In addition, most studies on the control of invading species have focused on single species invasions but co-occurring non-native plants could lead to continued re-invasion of less dominant species (Kuebbing et al., 2014, 2013). Moreover, it has been shown that repeated and long-term management activities or treatments may be necessary to overcome the cycle of re-invasion (Kettenring & Adams, 2011). Thus, we position our research within a social-ecological context with a diverse forest user population to evaluate the effects of multiple community-based management approaches on invasive plant abundance and non-target effects in working forests.

In this paper we ask, what is the influence of current (traditional) land management approaches on invasive plant abundance, plant community richness, and aboveground plant productivity compared to other, similarly low cost, adaptive management techniques? We conducted this study in Western Chitwan Valley, located in the southern Terai region of the lowlands of Nepal, which supports a mosaic of protected areas, rural agricultural farmland, and 21 locally governed community forests (CFs) within the buffer zone of Chitwan National Park, the first national park of Nepal (Bhattarai et al., 2017). In this study area, community forest management groups, composed of forest users and coordinated by an elected committee, routinely clear understory vegetation manually/mechanically by pulling and cutting, and leaving removed vegetation on the ground (a technique locally called "jungle cleaning"). Jungle cleaning is ubiquitously applied across all CFs in the region and is generally aimed at promoting the growth of grasses and small trees by removing undesirable vegetation (Sullivan, York, An, et al., 2017), yet the ecological effects or social intention of jungle cleaning have not been well documented (Chapter 1). The traditional vegetation removal method was not developed with the intention of controlling invasive plant species, and it could further exacerbate invasive plant spread due to rapid growth and regeneration often stimulated by mild disturbances, like cutting, which leads to continued propagation and re-invasion (Hiremath & Sundaram, 2005; Li et al., 2013; Mandal & Joshi, 2014).

As an alternative to this traditional management method, Murphy et al. (2013) suggested a modified mechanical approach to invasive plant control based on experimental studies in neighboring but similar forests in India. This modified mechanical approach is also low cost and low technology, and asks forest users to remove only invasive plants (rather than all herbaceous vegetation) by first disentangling and uprooting individual stems, then immediately placing the biomass in a burlap bag to prevent dropping reproductive plant remnants. Forest users are then asked to bury vegetative remnants at least 12 inches beneath the soil surface to prevent re-sprouting.

We experimentally assessed the effect of repeated mechanical treatments (modified or traditional) and prescribed fire on areal cover of six invasive plant species (three of which are the most aggressive and problematic invasive plants in the world; (Lowe, Browne, Boudjelas, & De Poorter, 2000) and native plant regeneration. We measured ecological outcomes of these interventions in two seasons, in June prior to the summer monsoon, and during the peak forest resource harvest period in October, after the summer monsoon. We expected the traditional approach to be ecologically unsuitable for controlling invasive plant species because it would promote, rather than deter, invasive plant growth. Similarly, we hypothesized low-intensity, prescribed fires will contribute to invasive plant growth while simultaneously stimulating grass production. In contrast, we hypothesize that because the modified approach targets only invasive plants, its application will encourage native, desirable vegetation to regenerate and fill the vacated niche created by removing invasive plants. We expect that when modified mechanical methods are combined with prescribed fire, grass production will be stimulated by the fires and invasive plants will be suppressed by the mechanical treatment. Therefore, we expect the combination of modified treatment and prescribed fire to be the most effective method for controlling invasive plants.

Finally, given the nature of rapid regeneration of invasive plants and the fertile growing conditions available in this sub-tropical climate, we anticipate that the effect of any treatment technique would be temporary and that repeated applications of all treatments will be necessary to curb the growth of multiple invasive plant species over time (Kettenring & Adams, 2011; Kuebbing et al., 2013). Therefore, we assess whether the ecological efficacy of each treatment approach (as it relates to reducing invasive plant abundance) increases over multiple treatment events.

METHODS AND STUDY DESIGN

Study site. We conducted this research in five of the 21 locally governed community forests located in the buffer zone of Chitwan National Park in Western Chitwan Valley, Nepal.

This region is characterized as a subtropical, lowland ecosystem and is known as a biodiversity hotspot for its extensive forest and grassland habitat for threatened mammals like the one-horned rhinoceros (Lehmkuhl, 1994) and Bengal tiger (*Panthera tigris tigris*). The lowland plains of Nepal are known for their fertile and arable soils, seasonal monsoons from June to September, relatively dry winters, and precipitation that ranges from 1000 mm to 2500 mm throughout the year (Siwakoti, 1970).

In rural areas of Chitwan, most people engage in some form of subsistence-based farming or agricultural land-use (Matthews, Ganesh, & Chhetri, 2000). The agricultural land area in the center of Chitwan is naturally bounded by the Narayani and Rapti rivers, along which most of the buffer zone CFs are established and function as a transition area between the protected region of Chitwan National Park and agricultural land (Figure 2.1). Unlike the strictly protected national park, CFs are used heavily by community members to collect natural resources, gain access to the river, or as sites for recreational activities and tourism. The CFs are locally managed by separate groups of elected forest managers referred to as the management committees who are responsible for forest management decision-making and establishing regulations for human access and utilization of CFs (Nagendra et al., 2008; Nagendra, 2002; Reyes-García et al., 2006; Thoms, 2008). These management regulations are also reviewed and approved by the District Forest Office, a subset of the Ministry of Forest and Soil conservation and a regulatory body of Nepal’s central government (Ministry of Forest and Soil Conservation 2017).

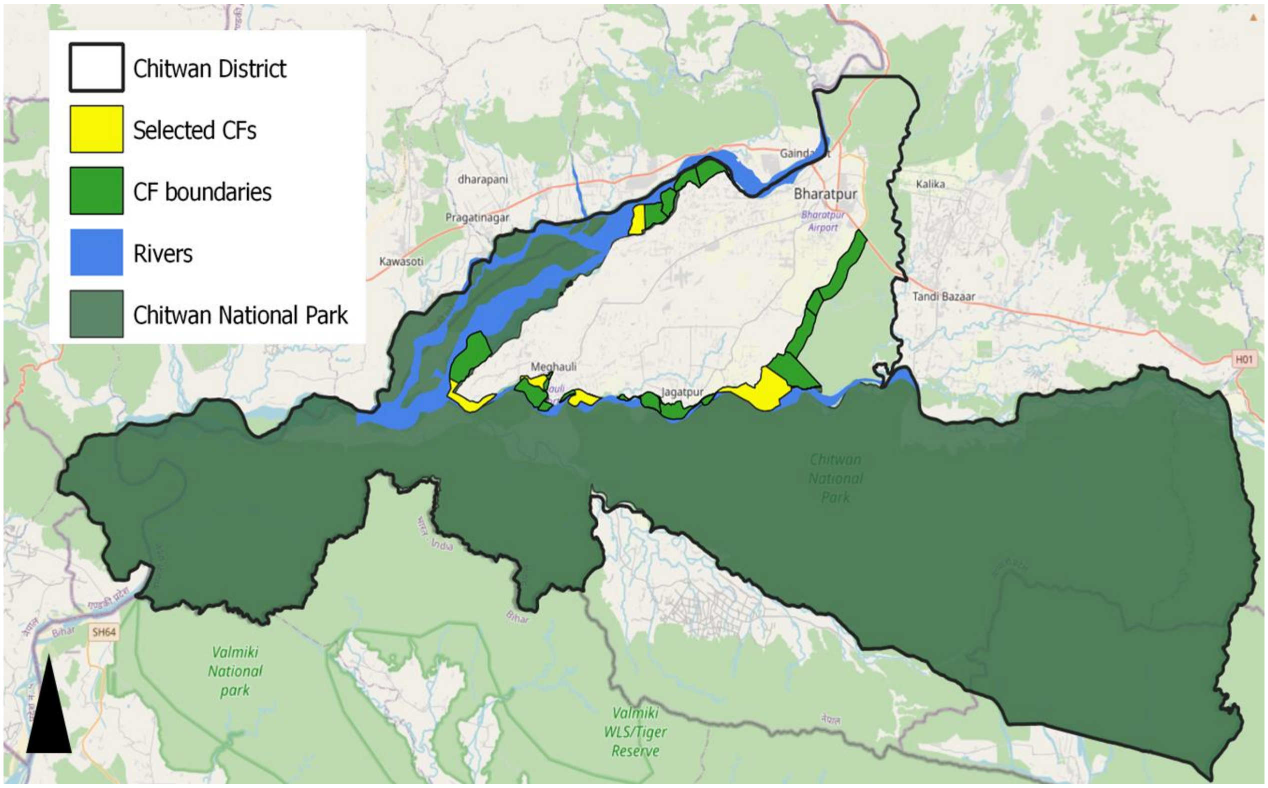

Figure 2.1. Map of the five selected intervention study sites (highlighted in yellow) among the other buffer zone community forests (bright green). Chitwan National Park (dark green) is nested within the southern and western edges of the entire Chitwan district (bolded black line).

CF selection for intervention activities. We selected CFs for the experimental intervention that had evidence of extensive plant invasion and a history of traditional vegetation management activities. To gauge CF manager forest practices prior to conducting the intervention experiment, in 2014, we evaluated responses to a detailed survey questionnaire regarding management practices, forest regulations, and the history of CF establishment. We found that all the elected managers of the 21 CFs in the study area engaged and organized forest resource users in some sort of vegetation removal technique (jungle cleaning), either through volunteer agreements or with payment. We then evaluated an ecological survey conducted from 2013 to 2015 to determine which forest types were prone to plant invasion (Chapter 1). Relative to grasslands and *Shorea robusta* forest, riverine forests, those that are frequently inundated by flood waters and accessed more frequently by forest users, have higher invasive plant abundance and higher cover of the most prolific invasive plant, *Mikania micrantha* (Chapter 1). Within riverine forests, we inquired about the CF managers' level of interest in and CF member willingness to maintain multi-year treatments and selected five CFs to participate in the intervention in November 2015.

The five selected forests represent a sample of CFs with engaged forest managers and resource users in environmentally similar forest types with a high abundance (present in >60% of the forest) of at least one notable invasive plant from the IUCN's list of the world's worst invasive species (Table 2.1). In addition, at least 6% of the forest floor of the selected CFs underwent some sort of jungle cleaning or plant clearing in the past year, and were frequently accessed by forest resource users within the past year to collect natural resources, predominantly fodder for domestic animals, firewood for fuel, and thatch (Table 2.1).

Table 2.1 Environmental and forest management characteristics in each of the five CFs selected for the intervention. The overall percent cover of the dominant invasive plant species, *Mikania* and *Chromolaena*, were assessed from an ecological survey of plots spaced 50 m apart across the entirety of each CF. The presence of *Ageratum*, but not percent cover of the species, was collected across the CFs in the same manner. All CFs are referenced by their randomly assigned numeric identifiers. We administered a spatially referenced, tablet-based survey questionnaire to CF management committee members in 2014 to determine how much of the forest floor was cleared in the past year (i.e. 'jungle cleaning'). We also administered a survey questionnaire to household representatives in 2013-2014 to determine how much of the forest was used to collect natural resources. Additional details about the surveys are available in Chapter 1.

Feature		**Community forest**				
		CF 1	**CF 2**	**CF 3**	**CF 4**	**CF 5**
Dominant soil type		Gleyic cambisol	Gleyic cambisol	Gleyic cambisol	Gleyic cambisol	Gleyic cambisol
Overstory tree species		*Bombax ceiba, Shorea robusta, Dalbergia sissoo*	*Dalbergia sissoo, Maesa chisia, Treweria nudiflora*	*Bombax ceiba, Treweria nudiflora, Dalbergia sissoo*	*Bombax ceiba, Treweria nudiflora, Dalbergia sissoo*	*Bombax ceiba, Treweria nudiflora, Dalbergia sissoo*
Understory herbaceous species		*Imperata cylindrica, Clerodendrum inforunatum, Desmodium triflorum*	*Oplismenus burmanni, Panicum notatum, Saccharum spontaneum*	*Clerodendrum infortunatum, Imperata cylindrica, Pogostemon benghalensis*	*Imperata cylindrica, Saccharum spontaneum, Ziziphus nummularia*	*Imperata cylindrica, Saccharum spontaneum, Mimosa pudica*
% of forest invaded by *Mikania*, *Chromolaena*, or *Ageratum*		67	89	100	73	67
Distance to river (m; mean ± s.d.)		404.88 ± 328.39	395.21 ± 200.31	1098.49 ± 320.35	240.17 ± 147.93	185.21 ± 120.24
% cover (mean ± s.d)	*Mikania micrantha*	1.99 ± 6.76	21.71 ± 22.06	26.60 ± 24.61	22.67 ± 27.63	5.16 ± 9.02
	Chromolaena odorata	9.18 ± 11.01	4.80 ± 7.27	9.04 ± 9.02	7.75 ± 11.36	5.46 ± 7.43
	Ageratum spp.	NA	NA	NA	NA	NA
% of community forest accessed	Fodder collected	22	20	53	32	40
	Firewood collected	27	19	63	32	40
	Thatch collected	0	0	24	7	25
	Jungle cleaned	27	6	28	22	13

The selected CFs occur in deciduous riverine forests known for their productive, nutrient rich soil type (classified as Gleyic Cambisol) and seasonal flooding. Of the five selected community forests, four were in the southern border of Western Chitwan Valley along the Rapti river and are characterized by an understory of dense grasses and an overstory of mixed sub-tropical trees, notably dominated by *Bombax ceiba*. One CF is located along the northern border of the valley, along the Narayani river, and is a riverine mixed forest dominated by the deciduous tree, *Dalbergia sissoo*. Dominant understory species across the study area include grasses (*Imperata cylindrica*, *Panicum notatum*, *Oplismenus burmannii*, and *Saccharum spontaneum*) and a dense herbaceous community consisting of perennial shrubs (*Ziziphus nummularia* and *Clerodendrum infortunatum*) and creeping, leguminous annuals (Table 2.1).

Target invasive plant species. Ecological control of one invasive plant could lead to the proliferation of less dominant invaders, therefore, we chose to target the removal and monitor the abundance of six invading plants in our study area: *Mikania micrantha, Chromolaena* odorata, *Ageratum* houstonianum, *Ageratum* conyzoides, Lantana camara, and Parthenium hysterophorus (Flory & Bauer, 2014; Kuebbing et al., 2014, 2013). Hereafter, the dominant invasive species are referred to by genus only. Of these invasive species, the perennial plants, *Mikania*, *Chromolaena*, and Lantana, are on the IUCN’s list of world’s worst invasive plants and the annual plants, *Ageratum* and Parthenium, are aggressive invaders known to contain chemical irritants that are either toxic to livestock or impact human health (Lowe et al., 2000). In the selected CFs, at least one of the three most abundant invasive plants (*Mikania*, *Chromolaena*, *Ageratum*) are present in 67-100% of each forest (Table 2.1).

Mikania, a rapidly growing shade-intolerant vine, is one of the most problematic invasive plants in Nepal and around the world. *Mikania* establishes in plantation crops and disturbed forests and is a prolific seed producer, however it more commonly propagates from the root nodule – making it very difficult to remove effectively through manual cutting (Kuo, Chen, & Lin, 2002; Swamy & Ramakrishnan, 1988). *Mikania* has immense regenerative capacity and ability to overgrow forest canopies and effectively smother trees. As a fast-growing invasive plant, *Mikania* can quickly respond to newly available resources brought about by disturbances, especially fire (Swamy & Ramakrishnan, 1987, 1988).

Our study area has been invaded by two other notable species, *Chromolaena* and *Lantana* (Table 2.1), that are both globally invasive plants and are species of major concern throughout forests in Nepal (Bharat Babu Shrestha, 2016; U. B. Shrestha, Sharma, Devkota, Siwakoti, & Shrestha, 2018). *Chromolaena* is a fast-growing, shade tolerant perennial shrub (Chudamani Joshi et al., n.d.; Mandal & Joshi, 2014). Similarly, *Lantana* grows rapidly, creates dense thickets of thorny brush, and re-sprouts readily after mild fires (Hiremath & Sundaram, 2005; Sundaram, Krishnan, Hiremath, & Joseph, 2012).

There are two invasive congeners from the genus *Ageratum*: *Ageratum conyzoides*, known for its toxicity to livestock animals, and *Ageratum houstonianum*, a prolific invader typically found in agricultural areas (Singh, Singh, Sharma, & Raghubanshi, 2011). Both species are multi-branched, herbaceous annual plants that are morphologically similar and difficult to distinguish prior to the flowering phase, at which time, *A. conyzoides* tends to produce pale blue/white flowers and *A. houstonianum* tends to exhibit flowers with darker blue pigment. To prevent misidentification of the two often co-occurring invasive plants, we have combined them into the category *Ageratum spp*.

Parthenium is a short-lived and small-statured herbaceous plant with high production of pappus seeds that encourage its dispersal ability by wind (Timsina, Shrestha, Rokaya, & Münzbergová, 2011). *Parthenium* is often considered an agricultural weed that infests roadsides and abandoned pastures. This plant has only recently been documented within Chitwan National Park and the surrounding community forests since 2012 (Shrestha, Shabbir, & Adkins, 2015; Shrestha, 2012). Notably, *Parthenium* is toxic to livestock and impacts human health by causing dermatitis or respiratory infections (Evans, 1997).

Intervention design and data collection. Given resource-user familiarity with jungle cleaning and the use of prescribed fires throughout the study area, we aimed to integrate and build upon these existing management techniques and to evaluate the ecological efficacy of traditional land management compared to modified approaches. To examine the efficacy of two mechanical control treatments (modified and traditional) and prescribed fire on invasive plant abundance and native plant community regeneration, we designed four intervention treatments. These treatments include: 1) Traditional method with prescribed fire, 2) Traditional method without prescribed fire, 3) Modified method with prescribed fire, 4) Modified method without prescribed fire. In November 2015, we selected the locations of all four experimental plots within five community forests, for a total of 20 treatment plots. The plots were aggregated within a 400 m x 400 m square area but were spaced at least 50 m from any other plot. Plots were 20 m X 20 m in area with an additional buffer of 5 m along each side where 1 m wide fire lines were constructed and maintained throughout the duration of the experiment (Figure 2.2). One of the four treatment combinations was randomly assigned to each plot.

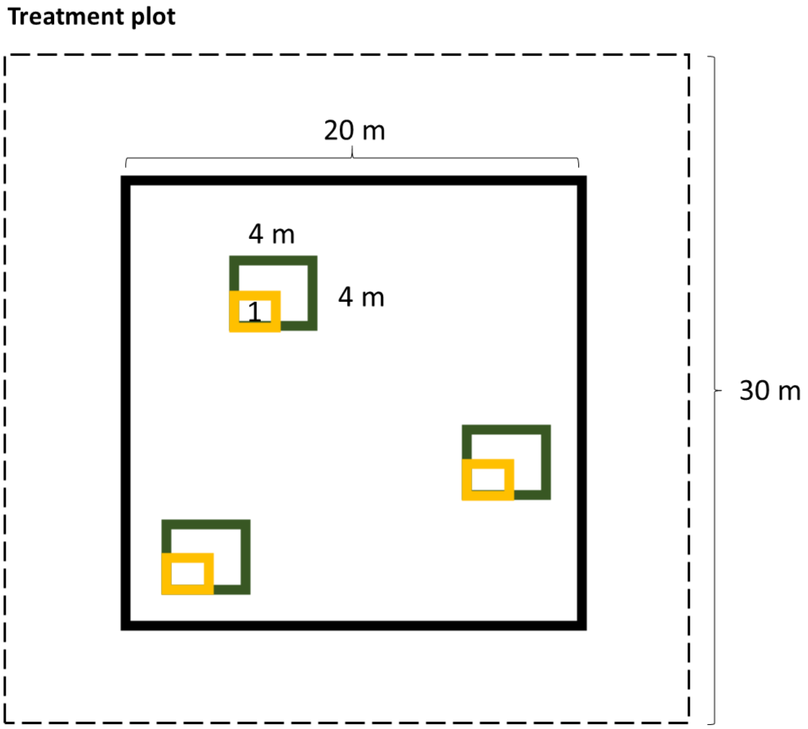

Figure 2.2. Diagram of treatment plot dimensions. Dotted lines represent the general buffer boundary around the plots where fire lines were constructed. Within the boundary of the buffer area we marked a 20 m X 20 m plot (bold black line) where the treatments were conducted. We placed 4 m X 4 m quadrats (greens) with nested 1 m X 1 m sub-quadrats (yellow) within randomly throughout each plot.

Data collection. To assess understory plant cover, we randomly assigned three locations to place a 4 m X 4 m quadrat within each plot. In each quadrat, we measured percentage plant cover using the following estimated cover classes: 0%, 0-25%, 25-50%, 50-75%, 75-100%, or 100% which were later converted to midpoint percentages. We estimated percent cover of the six invasive plant species, *Mikania micrantha, Chromolaena odorata, Ageratum houstonianum, Ageratum conyzoides, Lantana camara,* and *Parthenium hysterophorus,* and identified all other plants to species within each quadrat. We assessed forest canopy cover using a spherical densiometer and measured the percentage of squares occupied by overstory vegetation (Lemmon, 1956). In the southeast corner of each quadrat we nested a 1 m X 1 m sub-quadrat and determined the total stem count of all invasive plants, to capture post-treatment vegetative coppicing. During the final data collection (October 2018), we clipped all aboveground biomass, excluding trees and saplings, within each sub-quadrat and separated invasive plants and all other plants by growth form (woody shrubs, grasses, or /forbs). Biomass was dried at 75° Celsius for a 48-hour period and weighed to the nearest 0.1 gram. We collected plant biomass and measured stem density and percent plant cover in two additional, randomly placed plots within each CF as an untreated control outside of the intervention plots, referred to as the reference plots.

Treatment and data collection timeline. To assess the effect of different treatment techniques, we collected plant cover data for three consecutive years in the pre-monsoon (June) and post-monsoon (October) season from 2016 to 2018 (Figure 2.3). In each year, we aimed to capture the treatment effect prior to the growing season (June measurements) and the residual treatment effect after the growing season (October measurements) as well as the cumulative effect of multiple treatment applications over time relative to pre-treatment measurements. There is minimal plant growth during the dry, pre-monsoon season but immediate and rapid vegetative growth of all plants during the monsoon/growing season (June to September) (Bhattarai, Vetaas, & Grytnes, 2004; Nayava, 1974). These time periods (before and after monsoon season) represent climatic shifts that are socially meaningful because forest users are rarely actively collecting resources in the forest during the heavy rains. Thus, we assess invasive plant responses to intervention treatments in times that overlap with intense human land use and modification -

when invasive plants might have the greatest impact on ecological properties as well as the availability of forest plants for resource collection.

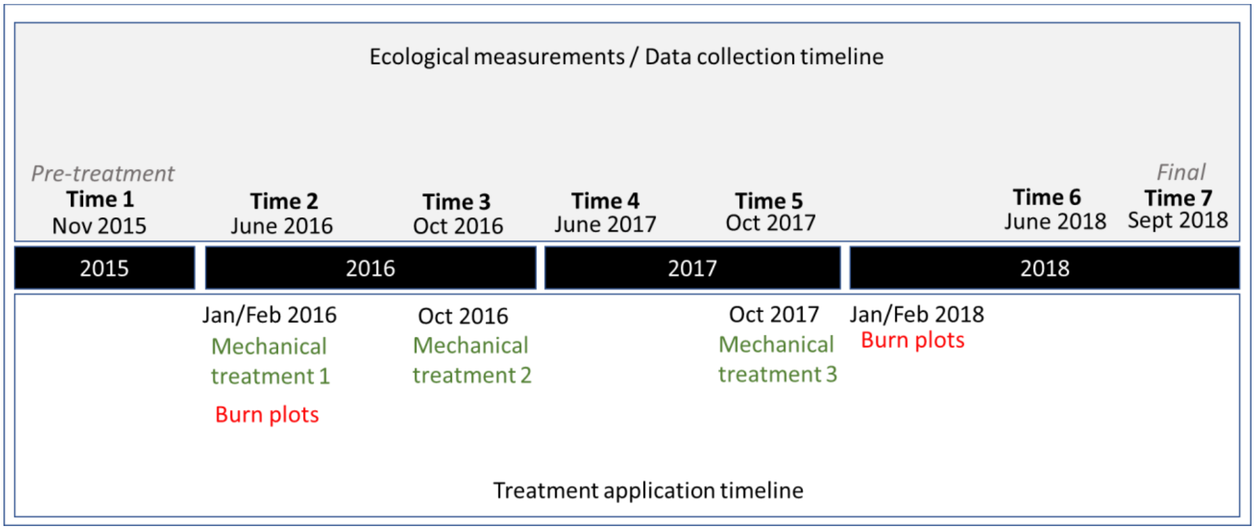

Figure 2.3. Intervention treatment and ecological measurement timeline. Dates on the top of the figure (time 1 through 7) indicate when the intervention plots were measured. Dates on the bottom of the figure indicated when the different treatments were conducted. Mechanical treatments were applied in January 2016, October 2016, and October 2017. Fire treatments were applied and January of 2016 and 2018.

Mechanical removal treatments were applied at three time points within the same plots. The first application occurred in January/February 2016, the second application occurred 10 months later (September/October 2016), and the third application occurred 22 months later (October 2017). Fire treatments were applied during the dry, winter season in January 2016 and January 2018. Ecological sampling occurred once prior to the mechanical treatments (December 2015/January 2016; referred to as 'pre-treatment'), and at six other times after the first treatment in June and October 2016; June and October 2017; June and October 2018 (Figure 2.3).

Each plot corner was recorded using a GPS and by photo-documentation, but plots were never permanently marked within the forest to prevent inadvertently encouraging or deterring visitors. CF managers and forest guards were consulted during the treatment plot selections and were asked to report any anthropogenic events or natural disturbances that took place within the plots. We expected to encounter some human activity within the treatment plots because these experiments were carried out in regularly accessed community forests. Some plots were accidentally burned by forest users but were replaced and re-sampled within two months of the start of the study. Plots along the Rapti river were severely flooded during the June-October monsoon season in 2017. In CF 1, after severe flooding in 2017, some plots were re-vegetated with bamboo seedlings by the CF management committee.

Mechanical treatments. One of the main goals of this intervention study was to find low-cost technologies that could feasibly be carried out by CF users as a means of managing invasive plants in the long-term. For this reason, all mechanical treatments were rooted in community-based practices and were conducted by CF users. Forest users were recruited by the forest guards, researchers, or management committee as paid volunteers to participate in the applications of all mechanical techniques. Some of the same volunteers were recruited to implement all three treatment applications (June 2016, October 2016, and October 2017) but most volunteers participated in two intervention events on average. Volunteers were compensated commensurate to a daily labor wage in Nepal (approximately $4 USD) and were provided food and drinks.

Traditional. The traditional method was carried out only by the CF volunteers so that researchers could observe and not influence how the process of jungle cleaning is typically conducted. When implementing the traditional approach, researchers observed that all plants were hand-pulled or cut at the stem and discarded within the plot in piles, including native and invasive plants but excluding mature trees and saplings. The traditional method was done on the same date as the modified treatments and with the same volunteers. At the end of each intervention event, some volunteers returned to the traditional method plots to collect any desirable plant species, typically fodder and grass, to take back to the village to feed their domesticated animals.

Modified. To conduct the modified method, research members instructed and assisted volunteers in identifying and removing only the six target invasive plant species in each CF. The instructions to implement the modified method were to remove invasive plants by untangling them from other vegetation, uprooting the plant, immediately placing in a burlap bag to prevent dropping reproductive remnants of the plant, and then burying them to a depth greater than 12 inches below the soil. In all CFs, men volunteers typically self-organized to dig the hole for burying vegetation while women conducted the mechanical treatments. After the hole was constructed, men typically helped to conduct the traditional method.

In some CFs, plots were covered by thorny and impenetrable, native shrubs: *Ziziphus nummularia* or *Ziziphus mauritiana*. In these plots, volunteers could not remove the invasive plants (particularly, *Mikania* which was intertwined with the thorns of the shrub) without also cutting the shrub. Consequently, volunteers cut *Ziziphus* at the base of the stem and buried it along with the invasive plants in the treatment plots where *Ziziphus* was abundant.

Prescribed burning. All prescribed fires were conducted in the presence of a forest guard and with an approved letter from the Chitwan: District Forest Office, Government of Nepal because fire application is restricted throughout the community forests. Prescribed fires were set by at least one researcher and one forest guard by igniting small piles of accumulated leaf litter and scattering the litter throughout the plot. This manner of setting fires was intended to emulate how forest users would initiate small fires in the forest with the resources available to them. Fires burned at a low intensity and ignited only the forest undergrowth.

To prevent unintentional fires within the plots, we constructed a fire line within the 5 m buffer around the perimeter of each 20 m X 20 m treatment plot. Initial fire lines were created in January 2016 and were maintained by forest user volunteers and researchers once each year throughout the study period. The fire line was 1 m in width and scraped to bare mineral soil where possible and adjusted around the plots to accommodate trees and large shrubs that were difficult to remove.

ANALYTICAL METHODS

Given that some studies have shown areas with variable species composition are more resistant to invasion, we counted the total number of individual species within the 4 m x 4 m quadrats to estimate average plant richness for each plot (Kennedy et al., 2002). However, to prevent inflating the richness calculation with nuisance plants that we were aiming to reduce, we excluded the top six invasive plants from our measurement.

To determine the effect of mechanical and prescribed fire treatments on plant community composition and to account for the variation within each community forest, we used a hierarchical spatial structure model of plot nested within site (CF) (Hofmann, 1997). Models included invasive plant species cover (*Mikania*, *Chromolaena*, and *Ageratum spp.*), plant richness, and biomass as the response variables. Of the six focal invaders, we modeled only the abundance of *Mikania, Chromolaena* and *Ageratum spp.*, because the other invasive plants (*Parthenium* and *Lantana*) were often undetected or occupied very few plots in the study. We assessed the effect of treatments during the pre-monsoon (June) and post-monsoon (October) season separately and compared them to the pre-treatment plots (no treatment applied at that time). We could not assume independence of the data because plots were repeatedly measured over several seasons, thus we violated the assumptions of a generalized linear model (Breslow, 1996). Therefore, we used a mixed-effects model to account for any correlations among the repeated measurements. Fixed-effects within the model included the mechanical treatment (modified, traditional, no treatment) by season (before or after the monsoon) and fire treatment (burned or not burned), as well as the interactions between mechanical and fire treatments. In total the five CFs had four treatment plots with three nested quadrats, for a total of 60 observations. The 60 quadrats were observed across seven time periods (Figure 2.3) resulting in 420 observations. Plot was nested within site as a random factor. Statistical analyses were performed using the *lme4* package and models were fitted using the ‘lme’ function and REML method in R software environment (version 3.6.1).

We collected plant biomass separated by growth form as a means of estimating plant productivity of desirable or nuisance plants within the different treatments. Since biomass collection is a destructive procedure (removes all aboveground shoots and stems), data was only collected during the final data collection in October 2018. We compared plant biomass within treatment plots and external reference plots using linear mixed-effect models.

RESULTS

In this study, we examined the relationship between the intervention treatments and seasonal re-growth of the top three invading plants: *Mikania*, *Ageratum*, and *Chromolaena*, to identify to what extent forest management practices (traditional and modified approaches) influence invasion patterns. Given that seasonal plant dynamics across community forests shapes both the ecological and social properties of those natural systems (i.e. plant growth and resource availability), we assessed the impact of the intervention methods (mechanical and prescribed fire) before and after the monsoon season, when forest users are interacting with and removing forest resources more often.

We expected that the mechanical intervention treatments would have a significant negative effect on invasive plant abundance during the pre-monsoon season, but this effect would not be apparent in the post-monsoon season. Further, we hypothesized that the combined effect of burning would decrease invasive plant abundance in modified plots but would stimulate root or stem coppicing and thus increase stem density. At the same time, we hypothesized that plant community composition (richness of non-invasive and native plants) would increase following the modified intervention method because it would have fewer non-target effects on surrounding vegetation than the traditional method. We hypothesized that invasive plant biomass would decrease significantly in the modified method, where only invasive plants were targeted, but would be higher in the surrounding untreated forest. Further, we anticipated that plant biomass may be reduced in traditional method plots relative to modified method plots, since the traditional treatment type removed all vegetation, regardless of invasion status, within the plot.

Treatment effect on invasive plant abundance (cover). Overall, we found that total invasive plant cover, which is the sum of the abundance of all six of the target invasive plants, was significantly and negatively affected by both the traditional and modified intervention treatments at the p=0.05 level (Table 2.2). We hypothesized that the effect of the mechanical treatments would not be observed in the post monsoon season due to the drastic increase in plant productivity. Rather, we found that invasive plant cover was significantly reduced in both the pre and post monsoon season for both mechanical treatments. However, when considering the cover of the top three invasive plants separately, only the cover of one invasive plant, *Mikania,* was significantly and negatively affected by mechanical treatments.

Mikania micrantha is the dominant invader across all selected community forests. This prolific vine is capable of vegetatively coppicing at the root node within a few days after cutting (Li et al., 2013). For this reason, we hypothesized cutting and discarding plants within the traditional plots would unintentionally exacerbate *Mikania* growth relative to the modified plots. However, we found that both mechanical treatments (modified and traditional approaches) significantly reduced *Mikania* cover in the pre-monsoon season (June) measurement (Table 2.2). Further, we found that the traditional method also maintained a lower cover of *Mikania* through the post-monsoon season compared to plots that had not undergone a treatment. Unlike *Mikania*, overall cover of other invasive plants, *Ageratum spp.* and *Chromolaena*, was not affected by either of the mechanical treatments

Table 2.2 Linear mixed-effect model results. Results of mechanical treatment methods (traditional, modified, no treatment) and one prescribed fire treatment (burned or not burned) separated by season of measurement (pre or post-monsoon season) on variables related to invasive plant cover and stem density (counts). Standard errors are in parentheses below coefficients.

	----- Cover -----				----- Stem counts -----			
	a) *Mikania*	b) *Ageratum*	c) *Chromolaena*	d) Total invasive plant	e) *Mikania*	f) *Ageratum*	g) *Chromolaena*	h) Total invasive plant
Intercept	**34.58** ***	**15.00** ***	**9.17** ***	**64.0** ***	**6.75** ***	3.86	0.62	11.68
	(4.35)	**(2.79)**	**(2.35)**	**(8.11)**	**(2.28)**	(6.84)	(0.33)	(7.62)
Fire (Burned vs. Not burned)	1.67	6.13	-0.28	4.6	3.49	**27.94** **	-0.10	**30.57** **
	(6.77)	(3.48)	(2.38)	(9.08)	(3.88)	**(10.97)**	(0.50)	**(12.35)**
Modified method pre-monsoon (vs. no treatment)	**-13.69** ***	-4.18	-3.23	**-24.9** ***	-3.58	12.14	-0.51	7.51
	(5.26)	(2.74)	(1.97)	**(6.95)**	(3.09)	(8.94)	(0.42)	(9.91)
Modified method post-monsoon (vs. no treatment)	-3.41	-3.34	-3.23	**-14.6** **	-1.38	3.92	-0.45	1.54
	(5.26)	(2.74)	(1.97)	**(6.95)**	(3.11)	(8.94)	(0.43)	(9.96)
Traditional method pre-monsoon (vs. no treatment)	**-12.02** **	-4.73	-2.12	**-19.1** ***	-1.68	5.37	0.39	4.35
	(5.26)	(2.74)	(1.97)	**(6.95)**	(3.09)	(8.94)	(0.42)	(9.91)
Traditional method post-monsoon (vs. no treatment)	**-10.91** **	-3.06	-0.73	**-14.1** **	-0.15	4.79	-0.10	4.33
	(5.26)	(2.74)	(1.97)	**(6.95)**	(3.09)	(8.94)	(0.42)	(9.91)
Fire * Modified method pre-monsoon	-6.37	-6.11	-1.54	-8.3	-2.16	-28.63	0.11	-29.27
	(9.57)	(4.91)	(3.37)	(12.84)	(5.49)	(15.49)	(0.70)	(17.45)
Fire * Modified method post-monsoon	-10.81	-6.11	-0.15	-10.3	-3.44	-28.97	0.10	-31.03
	(9.57)	(4.91)	(3.37)	(12.84)	(5.49)	(15.49)	(0.70)	(17.48)
Fire * Traditional method post-monsoon	5.28	5.83	3.33	15.3	5.04	-12.22	1.09	-5.84
	(6.48)	(3.47)	(2.65)	(8.34)	(3.96)	(11.79)	(0.59)	(12.80)

Statistical differences reported as **p<0.05; ***p<0.01

We hypothesized that burning would promote invasive plant cover in the traditional method plots because the remaining root stems and vegetative remnants would be more likely to propagate. Further, we expected that fires in modified treatment plots would release newly available nutrients that would encourage re-growth of the intact grass and native plant community and deter invasive plant propagation (Kennard & Gholz, 2001). However, we did not observe an effect of the burn treatment nor an interaction between the burning treatments and either mechanical intervention on any of the invasive plants (Table 2.2).

Given that the prescribed burns were relatively mild and insufficient fuel load prevented the fires from carrying across the plots successfully, we were not surprised to find that the prescribed burn treatments had no effect on total invasive plant cover or *Mikania* cover (Table 2.2). On the other hand, total stem density of all invasive plants increased in plots that underwent burns. The total increase in stem density was largely driven by the abundance of *Ageratum* stems, an annual plant, rather than stem-coppicing by perennial plants (*Mikania* and *Chromolaena*). We hypothesized that modified treatments in combination with prescribed fire would discourage plant invasion while invasive plant cover in traditional treatments would be exacerbated by fire, but we did not find significant interactions between either mechanical treatment and prescribed burning on invasive plant cover or stem counts.

Repetitive treatment effect on invasive plant abundance (cover). We hypothesized that over the three-year study period, as the number of mechanical treatment replicates increased, *Mikania* and other invasive plants would decrease over time regardless of the season of measurement. We found that the repeated application of the modified method significantly reduced *Ageratum*, *Chromolaena*, and total invasive plant cover but had no effect on *Mikania* cover over time (Table 2.3). Unlike the modified method, the repeated application of the traditional method only reduced *Chromolaena* cover. Meanwhile, the replication of burning had no effect on the cover of any of the dominant invaders.

Table 2.3. Linear mixed-effect model results of cover and stem density. Results of three replicated mechanical treatment methods (traditional, modified) and two replicated prescribed fire treatments on four response variables related to invasive plant cover: *Mikania* cover, *Ageratum* cover, *Chromolaena* cover, and Total invasive plant cover. Standard errors are in parentheses below coefficients.

	Mikania cover		*Ageratum* cover		*Chromolaena* cover		Total invasive plant cover	
Intercept	**25.09**	***	**15.04**	***	**10.12**	***	**53.50**	***
	(3.93)		**(2.59)**		**(2.22)**		**(7.75)**	
Burn replication	-2.48		1.42		0.32		-1.48	
	(2.58)		(1.33)		(0.91)		(3.47)	
Modified replication	0.28		**-2.18**	***	**-2.21**	***	**-4.12**	**
	(1.54)		**(0.81)**		**(0.58)**		**(2.04)**	
Traditional replication	1.78		-0.38		**-1.38**	**	1.06	
	(1.54)		(0.81)		**(0.58)**		(2.04)	

Statistical differences reported as **p<0.05; ***p<0.01

Treatment effect on plant community composition and productivity. When forest users apply the traditional method, they do not discriminate between removing invasive and native plant species, which can have unintended non-target effects on the surrounding plant community. For this reason, we expected the traditional method to reduce plant richness relative to untreated plots. However, we found that plant richness was higher in both modified and traditional method plots compared to untreated, reference plots in the surrounding forest (Table 2.4). At the same time, burning and the interaction between burning and mechanical treatments had no effect on plant richness relative to the surrounding forested area that had not undergone any treatments.

Table 2.4. Linear mixed-effect model results on plant richness. Results of two mechanical treatment methods (traditional and modified) and prescribed fire treatments (burned or not burned) on plant richness. Plant richness was surveyed within untreated, reference plots in the final ecological measurement conducted in October 2018. Invasive plants were excluded from plant richness calculations. Standard errors are in parentheses below coefficients.

	Plant richness	
Intercept	**14.38** **(1.14)**	***
Modified method (vs. no treatment)	**3.42** **(0.88)**	***
Traditional method (vs. no treatment)	**3.52** **0.865**	***
Fire (Burned vs. Unburned)	-0.08 (0.66)	
Fire * Modified method	0.68 (0.95)	

Statistical differences reported as **p<0.05; ***p<0.01

Though the intention of the traditional method was to promote desirable species and to deter undesirable plants, there was relatively little documented information about the effect of jungle cleaning (traditional method) on productivity. Therefore, we assessed plant biomass during the final data measurement, conducted in the post-monsoon season (October 2018), when plant productivity is usually at its peak. Given the intrusive process of slashing and cutting all vegetation (except trees) we expected the traditional method to reduce plant biomass relative to the modified method. Yet, we found that the mechanical treatments had no effect on grass, forb, or woody plant biomass (Table 2.5). Rather, invasive plant biomass was reduced in both mechanical treatments compared to untreated, reference plots.

Table 2.5. Linear mixed-effect model results on total biomass. Results of two mechanical treatment methods (traditional and modified), one prescribed fire treatment (burned or not burned), and the effect of no treatment (untreated, reference plots) on total biomass separated by growth form. Aboveground plant biomass was clipped within 1m x 1m sub-quadrats on the final data collection in October 2018. Standard errors are in parentheses below coefficients.

	Invasive biomass	Woody plant biomass	Grass biomass	Forb biomass
Intercept	**45.30 ***** **(5.65)**	57.48 (88.08)	**36.48 ***** **(12.49)**	**26.09 ***** **(4.87)**
Modified method (vs. no treatment)	**-18.25 ***** **(6.87)**	-13.78 (115.22)	-1.47 (13.21)	-4.19 (4.98)
Traditional method (vs. no treatment)	**-18.19 ***** **(6.32)**	169.59 (115.47)	0.86 (12.29)	-6.44 (4.99)
Fire (Burned vs. Not Burned)	6.16 (6.92)	-174.30 (116.37)	10.93 (13.27)	6.36 (5.25)
Fire * Modified method	2.36 (10.29)	278.63 (164.01)	7.54 (18.89)	-1.42 (7.58)

Statistical differences reported as **p<0.05; ***p<0.01

DISCUSSION

Community-based management practices that incorporate stakeholder perspectives, are led by community members, and are tested within a working landscape are more likely to garner support from community members; however, given the social and ecological complexities of resource management, these types of interventions have gone relatively unstudied in the context of species invasions. In this study, we aimed to identify the effects of current (traditional) land management practices and modified techniques that can be applied to control invasive plant abundance. We intended the results of this intervention to be used as a guide for combatting invasive plant spread in communities with access to fewer financial resources or technologies. At the same time, we wanted to assess to what extent existing land management approaches reduced, or potentially intensified, the spread of invasive plants.

Given the nature of invasive plants to consistently grow and overwhelm native plant communities, especially those surrounded by human-dominated landscapes, we aimed to evaluate treatment efficacy between seasons (before or after the monsoon) as well as the effect of multiple treatment replications (across the entirety of the multi-year study) to find feasible, long-term management solutions (Vilà & Ibáñez, 2011). The results presented here indicate that both mechanical treatments (traditional and modified approaches) can effectively reduce invasive plant abundance, however, the effect of mechanical treatments are species-specific. For example, *Mikania* cover was significantly reduced by both traditional and modified treatments while *Ageratum* and *Chromolaena* cover were not affected. Similarly, other studies have shown that plants may not respond consistently to the same treatment applications or multiple treatment applications over time (Flory & Clay, 2009). Though invasive species co-occurrences are common, surprisingly few studies focus on the management of co-occurring invasive plants (Davis, 2006; Kuebbing et al., 2013) even though the removal of some invasive plants can lead to the dominance of other opportunistic species (Mau-Crimmins, 2007; Pearson et al., 2016). Our finding, that predominant invading species respond differently to the same management treatments, though not surprising, suggests that these mechanical methods are not a panacea for comprehensive invasive plant management. Further, to optimize invasive plant management programs in the long-term, the replication of a treatment effect on all dominating invasive and non-target plants should be evaluated.

We expected that *Mikania*, the most prolific invader and vegetative propagator in the study area, would be exacerbated by the traditional method treatment, but we found that both the traditional and modified methods were able to effectively reduce *Mikania* cover. Surprisingly, *Mikania* had significantly lower cover in the modified method, but only during the pre-monsoon season which suggests that the residual effect of the modified method (in October) was less prominent than the traditional method. The residual effect of the traditional treatment may have carried into the post-monsoon season due to competitive interactions between native and invasive plant species since this method of cutting plants has been shown to stimulate the growth of other native or desirable plant species (McLaren & McDonald, 2003). It is likely that forest users and land managers implemented the traditional method because it positively influences the surrounding native vegetation or else there would not have been consistent application of this method across the study area.

Despite the seemingly destructive nature of removing/cutting vegetation in the traditional method, we did not detect non-target effects on native plant species composition or biomass. Rather, both the traditional and modified method increased plant richness and reduced invasive plant biomass. The traditional method appears to be effective in discouraging the growth of unwanted, invasive plants while maintaining the availability of native or desirable plant species in the short-term. However, when considering the repetitive application of treatments, modified plots were more likely to reduce invasive plant cover than the traditional practices. Thus, when land managers are exploring sustainable land management approaches, the modified method should be considered because it may be more successful at reducing invasive plant cover in the long-term, though it is more meticulous and time-consuming to apply in the short-term.

Similarly, other studies have shown the multiple treatment applications are necessary to prevent re-invasion of the study area by dominant or secondary invasive plants (Kuebbing et al., 2014; O'Loughlin & Green, 2017; Pearson et al., 2016).

Prescribed fire is a common, traditional management tool in this system, thought to promote grass growth for valuable thatch and fodder species (although fires are not officially permitted; (Bolton, 1975; Dhungel & O'Gara, 1991). Fires applied in slash and burn agriculture have been shown to increase invasive plants like *Mikania micrantha* and *Lantana camara* (Swamy & Ramakrishnan, 1987, 1988). However, we did not find a significant effect of fire or an interactive effect between fires and the mechanical methods on invasive plant abundance. This is likely due to the low intensity burn of the winter fires relative to the higher intensity burning of downed (slashed) trees and vegetation (Peterson & Reich, 2007). Though fires are not permitted in the community forests, they do occur relatively frequently in the national park and community forests, so it is promising to find that low-intensity fires are not directly linked to increases in invasive plants. However, forest users and managers should consider that fire intensity and seasonality can drastically alter plant community responses and should be applied with caution (Knox & Clarke, 2006, 2012).

Given the social and ecological threat of invasive plant species, land managers and researchers have started to embrace local-level, adaptive, and collective management approaches to uncover community-based management practices that will combat invasion (Miller & Schelhas, 2008; Plummer & Armitage, 2007). We found that mechanical treatment approaches, in particular the modified method, are able to effectively curb the rate of *Mikania* spread and may be more likely to discourage invasion after multiple treatment applications. Further, the traditional method (jungle cleaning approach), did not exacerbate the spread of invasive plants but it also did not stimulate native plant re-growth or biomass production. In the context of this study, both the modified and traditional method could be considered effective for reducing invasive plant abundance while having no detected non-target effects on native plant biomass or richness. However, the modified approach requires forest users to identify and strictly remove only invasive plant species, which makes it a more time-consuming approach and could influence how forest users and managers employ this strategy. Nonetheless, the efficacy of the modified approach may be more consistent than the traditional approach over time. Other studies have shown that forest user and manager buy-in is essential for effective collective management of invasive plants because community engagement and support of different management can influence whether management approaches are applied (Fernandez-Gimenez et al., 2008; Fischer & Charnley, 2012; Kelley et al., 2013). Future studies should be designed to consider the perceived efficacy of the traditional and modified approaches to determine whether perceptions will influence implementation.

CHAPTER 3

FOREST USER AND LAND MANAGER PERCEPTIONS OF COMMUNITY-BASED INVASIVE PLANT MANAGEMENT TECHNIQUES IN BUFFER ZONE COMMUNITY FOREST

ABSTRACT

The incentives and rationales for managing plant species invasions are influenced by the ways in which land managers and users perceive both the severity of the environmental problem and the ability of a management approach to overcome it. Because invasive species are relatively new environmental problems, they may not be perceived as having purely negative consequences and they may not be identified as an environmental issue that is surmountable. Differing perceptions of invasive species could delay their management at the local level. Further, in many rural areas and developing nations, relationships with natural resources are gendered (women are the dominant resource collectors) and governed by position (resource managers or users). These differing people-resource relationships can influence perceptions of land management strategies and invasive plant species. Yet, most invasive plant management studies do not explore how forest user and mangers interpret the effect of the management techniques, which could prevent land users and managers from applying certain techniques in the future. By investigating perceived efficacy of an ecological intervention, we can identify gaps between ecologically (suggested management) and socially appropriate (practiced management) control measures. We conducted a multi-year community-based participatory management study designed to assess both forest user and land manager perceptions of the efficacy of current forest management

practices (‘traditional management’) compared to low-cost alternative approaches (‘adaptive management’).

We found that resource managers and forest users had similar perceptions of what plants they consider to be invasive and why. While all interview groups reference plant harm and lack of utility as a reason for their invasiveness, women were more likely to cite the harm caused by the plant species. Further, invasive plant lists provided by forest users and managers were relatively similar to the target invasive species list. Though previous studies found that adaptive and traditional method approaches do not differ in invasive plant abundance, we found that the adaptive approach plots were all considered more preferable than the traditional method plots. Respondents gave similar rationales for treatment preference, all indicating that a lack of harmful plants and an abundance of useful plants is a main priority for all management techniques applied in the forest. Not only were adaptive methods preferred, they are also feasible and low-cost approaches that evolved from an already familiar, traditional approach. Management approaches, like this study, that integrate user and manager perceptions of community-based management practices are more likely to be adopted than methods that are difficult to access, employ, or are socially unacceptable.

INTRODUCTION

Effective invasive plant control requires consistent and collaborative management beyond local areas and across institutional boundaries (Graham et al., 2019; Hershdorfer, Fernandez-Gimenez, & Howery, 2007; Ma, Clarke, & Church, 2018; Masters & Sheley, 2006; Matzek, Covino, Funk, & Saunders, 2014; Reid et al., 2009). However, the incentives and rationales for managing plant species invasions are influenced by the ways in which land managers and users perceive both the severity of the environmental problem and the ability of a management approach to overcome it (Rydin & Pennington, 2000). Research from the adaptive management literature shows that implementation of restoration action often falls short of realizing goals, not because people necessarily disagree with the scientific ideas and management plans but because their perceptions of the goals or efficacy of the actions differ (Dreiss et al. 2017). Further, disconnect between management goals and actions could be even more of a barrier to successful management outcomes when applied to contested environmental issues, like introduced and invasive species (Benson & Stone, 2013). In addition, controversies around invasive species management can increase when management plans are not considered socially appropriate by stakeholders or they are not engaged in the decision-making process (Bhattacharyya & Larson, 2014; Crowley, Hinchliffe, & McDonald, 2017b; Shackleton, Richardson, et al., 2019). At the same time, there are gaps in our understanding of how to effectively manage invasive species in differing ecological and socio-cultural contexts because these species are relatively new to those environments (Norgaard, 2007; Simberloff, 2012).

Land managers are tasked with controlling and preventing the spread of invasive plants, particularly in national parks, reserves, and in the buffer zones that surround protected areas

(Foxcroft et al., 2017). Located in the transition region between protected areas and the urban fringes of agricultural, residential, and commercial land areas, buffer zones are designed to support local livelihoods and to engage stakeholders in wildlife conservation (Budhathoki, 2004; Martino, 2001). For this reason, buffer zones are heavily impacted by human use and disturbance which makes them highly susceptible to invasive plant species (Meiners & Pickett, 2013) that alter forest productivity and reduce the availability of natural resources (Liebhold et al., 2017). Invasive plants have been characterized as a transboundary natural resource management problem, because the vectors that encourage transport of invasive plants are not hindered by socially constructed boundaries like the confines of a buffer zone or protected area (Foxcroft et al., 2011; Graham, 2013; Riley, 2009). Studies have shown that areas with multiple land managers and diverse land use are more susceptible to plant invasions because the probability that all land managers will prioritize invasive plant control decreases, and uncontrolled areas will continue to spread invasive plants to neighboring locations (Epanchin-Niell et al., 2010). Further, as stakeholder interests, land use, and resource management priorities diversify, collective action is undermined and invasive plant interventions can be hindered (Epanchin-Niell & Wilen, 2015; Epanchin-Niell et al., 2010; McKiernan, 2017). Yet, other studies have shown that invasive plant management and collective action benefit when neighboring land managers have similar values and priorities for management (Graham, 2013; Graham et al., 2019; Meadows, Herbohn, & Emtage, 2013).

Similar to land managers, individual land users also consider the incentives for participating in land management and are less likely to engage in collective action if they have low confidence in their capacity to overcome the environmental problem (Yoon, 2011). Further, land users and managers tend to be more satisfied with management approaches that are already familiar to them, are considered easier to access, and are low-cost (Kelley et al., 2013; Ravnborg, 2004). For example, Marshall et al. (2016) found that successful invasive plant management was driven mostly by effective collective action rather than access to information about the environmental issue. Thus, community-based practices that take local concerns into consideration and involve stakeholders in management implementation can overcome these barriers to successful land management (Foster-Fishman, Cantillon, Pierce, & Van Egeren, 2007).

Land user differences in their level of knowledge or concern over invasive plant species can influence how they prioritize and support different management approaches (García-Llorente et al., 2011, 2008), which ultimately influences the success of invasive species control efforts. However, 'invasive species' are likely to be conceptualized differently across communities and cultures, and even scientific consensus on the interpretation of this term is lacking despite the global significance of species invasions (Boltovskoy, Sylvester, & Paolucci, 2018; Russell & Blackburn, 2017). Previous work on invasive species management in community-based contexts suffers from poor design, where researchers impose their predetermined definition for invasive species, or frame researcher-stakeholder disagreement of the invasive species problem as a ‘lack of awareness’ (Andreu, Vilà, & Hulme, 2009; García-Llorente et al., 2008). Instead, species that are considered invasive should be defined by the community *in situ* (Head, 2017) to first gauge consensus on species invasiveness (specifically, what species are considered invasive and why), which can be used to interpret forest user and manager rationale for their preferences towards different land management strategies and control efforts.

Despite the growing pool of literature on the social and ecological dimensions of invasive plant management (Vaz et al., 2017), by 2015, only 1% of papers published in invasion science have included the social dimensions of invasive plant management, and even fewer explore user or manager perceptions of management techniques that underpin the success of collective action efforts (Estévez et al., 2015). The few papers that have explored perceptions of invasive plant management indicate that a lack of community engagement and divergent management goals can stall management efforts or worse, ignite social conflict (Crowley et al., 2017a; Novoa et al., 2018). Thus, social-ecological studies on land management strategies conducted collectively by stakeholders (land users) are opportunely positioned to deliver twofold results by 1) identifying strategies for mitigating potential social conflicts regarding invasive plant management goals and 2) assessing the perceived efficacy of invasive plant management techniques and thus long-term support for the continued treatments. By exploring land user and manager perceptions of treatment efficacy, we can assess which management plans will be both ecologically beneficial and socially acceptable, to both forest users and managers.

In addition to the lack of literature on the human-dimensions of invasive plant management, most community-led collective action studies have occurred within the context of private landownership where there is a direct consequence of land management on the landowner. Missing from this literature are studies on the outcomes of management on collectively-managed public land, where there may be ambiguity in who initiates and who benefits from management decisions (Fischer & Charnley, 2012; Graham, 2013; Graham et al., 2019; Marshall et al., 2016; Niemiec et al., 2016; Yung, Chandler, & Haverhals, 2015). Given the complexities of effective land management, this paper explores the social, cultural, and institutional conditions under which land managers and users define, perceive, experience, and respond to invasive plant management in collectively managed public commons. In this study we ask, how can forest user and land manager perceptions of forest management inform invasive plant control and decision-making?

To answer this question, we explore the rationales and priorities of community-directed land management approaches towards invasive species control, the perceived efficacy of low-cost and low-technology interventions, and preferences towards desired land management outcomes in buffer zone community forests (CFs) surrounding a protected area in Nepal. Buffer zone CFs in this region are separately managed by locally elected committee leaders to meet diverse forest user needs. Because CFs are often spatially close to each other, and to protected areas, they provide an opportunity to explore how land management objectives diverge between multiple forest managers and among forest users (Wollenberg, Edmunds, & Buck, 2000). We conducted a multi-year community-based participatory management study designed to assess both forest user and land manager perceptions of the efficacy of current forest management practices (referred to as ‘traditional management’) compared to low-cost alternative approaches (referred to as ‘adaptive management’).

We aim to identify effective community-directed invasive plant management strategies by examining stakeholder prioritization of invasive plants, the intention and rationale of existing management efforts, and the perceived efficacy of traditional and adaptive management approaches. Differing levels of education, positions of power, and gender have all been found to influence perceptions and attitude towards invasive species (Bremner & Park, 2007; García-Llorente et al., 2011; Sharp et al., 2011). By first evaluating what plants forest users and managers consider to be invasive, we can identify to what extent these plants have been prioritized in current management plans and whether perceptions of these species differ between social groups. We hypothesize that rationales for what is considered a harmful or invasive species are influenced by gender and positions of power (land manager or individual land user). In tandem, an individual's or manager's familiarity with an invasive plant control technique, especially those that are low-cost and less labor intensive, have been shown to increase satisfaction with management (Kelley et al., 2013). Thus, regarding management preferences, we hypothesize that individuals who are more familiar with implementing management activities will show support for adaptive strategies because they are aware of the time and cost required to implement them. Further, we explore how management priorities in CFs differ between forest users and managers and discuss the trade-offs of implementing invasive plant management approaches.

METHODS

Study area and target invasive species. This study was conducted in Western Chitwan Valley, in buffer zone CFs surrounding Chitwan National Park (Figure 3.1). According to an ecological survey conducted from 2013 to 2015, 69% of the buffer zone CFs are covered by at least one invasive plant (Chapter 1). Six dominant invasive plants occur throughout the CFs: *Lantana camara, Mikania micrantha, Ageratum houstonianum, Ageratum conyzoides, Chromolaena odorata, Parthenium hysterophorus* (Chapter 2). These plants are not native to Nepal and are defined by the International Union for Conservation of Nature – Invasive Species Specialist Group (IUCN ISSG) as invasive because these species cause some sort of harm to the local economy, human health, or ecosystem properties. Of the 21 buffer zone CFs, 17 are dominated by grassland and diverse riverine tree species while the other four occur within the Sal (*Shorea robusta*) forest further from the river and seasonal floodwaters. We selected five riverine forest CFs for the intervention study as a representative sample of the main ecological type – riverine forests. The riverine forest type is characterized by deciduous tree species like *Bombax ceiba*, *Treweria nudiflora*, and *Dalbergia sissoo*. Hereafter, when referring to individual selected CFs we use their anonymous numeric identifiers (1, 2, 3, 4, and 5).

CF household use. In this study area, predominantly women (individual forest users) access the CFs to extract non-timber forest products like thatch, fodder, and fuelwood (e.g. fallen trees, branches, or woody stems), but at the same time, women are less likely to hold management or decision-making positions (Upadhyay, 2005). All trees are protected species in these forests and direct harvesting (unless it is fallen wood) is not allowed without a permit (Devkota, 2005; Jones, 2007; Mishra, 1982). CFs are accessed for both resource extraction and recreational use often in the form of tourism (guided jungle safaris and excursions), worship, or picnicking. Tourism is most common in forests near the national park border (Chapter 1). Since the establishment of the CFs, crop raiding of farmland by wildlife and wildlife-human conflicts have been a major issue of concern for local people (Nepal & Weber, 1995; Thapa, 2010). For this reason, CFs are generally bordered by a fence or some sort of barrier to limit wildlife movement outside the boundaries of the forest.

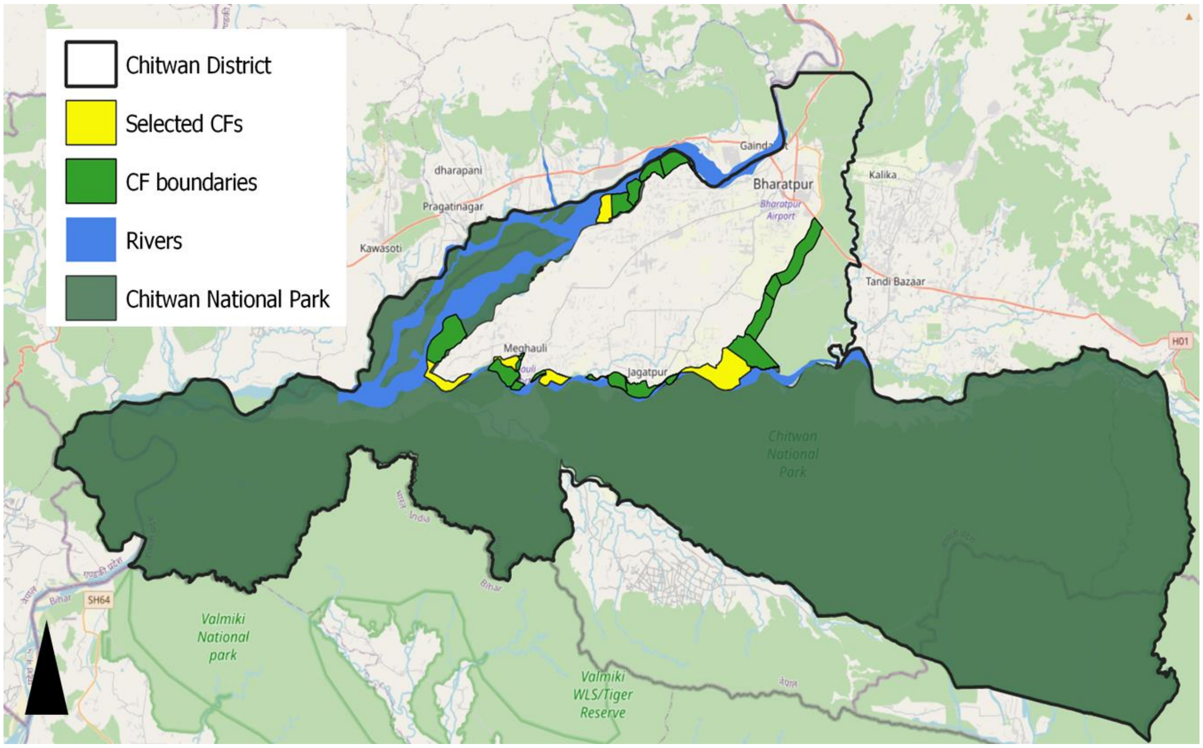

Figure 3.1. Map of the five selected intervention study sites (highlighted in yellow) among the other buffer zone community forests (bright green). Chitwan National Park (dark green) is nested within the southern and western edges of the entire Chitwan district (bolded black line).

From 2013 to 2014, a survey of 1235 households across Western Chitwan Valley was conducted. Briefly, this survey was administered to 1235 households that are located within 5 km of a CF (more details about survey approvals and conduct available in Chapter 1). Within those households, 65% of fodder is collected by at least one woman in the household, while 32% of fodder collection is carried out by at least one man in the household (Table 3.1). Within the five selected CFs, household use and extraction of forest products mimics these larger trends across Western Chitwan Valley.

Table 3.1. The percentage of households in 2013-2014 that were surveyed and reported collecting a resource in the past year in Western Chitwan Valley. One individual respondent from 1235 households was surveyed. Additional information about survey protocol provided in Chapter 1.

	Percentage (%) of households (N=1235)			
Resource collected	Collect the resource from any space	Collect the resource from a community forest	At least one woman from the household collects the resource	At least one man from the household collects the resource
Fodder	69	16	65	32
Thatch	19	10	16	10
Firewood	68	25	63	34

CF management. CFs are managed by democratically elected local officials (Stapp, Lilieholm, Upadhaya, & Johnson, 2015). In addition to the household survey, a survey of CF managers conducted from 2013 to 2014 found that all CFs implement strategies to improve forest condition. This survey was administered to 21 CF managers in 2014 with a 100% response rate (further details about survey approvals and conduct available in Chapter 1). Often, the conditions for forest management are approved by the District Forest Office, to ensure that forests are managed towards goals of forest sustainability and timber protection (Regmi & Garforth, 2010; Thapa, 2005). Forests may be accessed by forest guards or the Nepali army and may have restricted access or locally enforced forest regulations that permit or prevent the collection of some resources because the protection of forest products and endangered species are some of the country's national priorities (Heinen & Shrestha, 2006).

In this paper, we refer to land or forest resource users as any individual who accesses common land areas to collect, explore, recreate, or visit as an individual resource user. Land managers are regarded as individuals who were elected to positions within the CF management committee. Note that while land managers may also be resource users, we define them based on their position as manager.

Experimental intervention design. In 2015, we established a three-year multi-site intervention study in five selected CFs. We refer to any physical cutting/slashing of vegetation through hands-on or machine-based removal as a ‘mechanical’ method. We conducted two mechanical removal treatments (traditional or adaptive method) in combination with or without prescribed fire for a total of four treatment combinations. All treatments were applied by CF users once a year within 20 m x 20 m experimental plots that were aggregated within a 400 m x 400 m square area in each of the five CFs. Mechanical treatments were applied in January 2016, October 2016, and October 2017 and the prescribed fire treatments were applied in January/February 2016 and 2018. When conducting the interview group survey in January/February in 2018, plots had not yet received the second prescribed fire application and the most recent mechanical application was applied three to four months prior.

The combinations of mechanical and prescribed fire approaches resulted in four management strategies (specifics of how these were employed in the following section) that were applied in all five selected CFs:

1. Jungle cleaning (traditional method)
2. Jungle cleaning (traditional method) with prescribed fire
3. Invasive plant removal (adaptive method)
4. Invasive plant removal (adaptive method) with prescribed fire

All management strategies were conducted by a small group of forest user volunteers (6 to 10 people) from each CF each year, referred to as intervention participants. Brief details regarding the treatment approaches are provided below but for additional details about experiment design and assessment consult Chapter 2.

Traditional approach. To determine existing forest management practices, we evaluated the responses to a CF survey management questionnaire. Respondents from all 21 CFs reported managing the forest using a ‘jungle cleaning’ approach at least once in the past year. Jungle cleaning was ubiquitous across all 21 CFs and in the five selected CFs (Chapter 2). To apply jungle cleaning, forest users cut or slash all aboveground vegetation, excluding trees and saplings, and discard the remnants within the plot. Generally, jungle cleaning is a coordinated approach where CF managers organize a group of volunteers of forest users and members to remove vegetation, debris, or garbage in the forest once or twice per year (Sullivan, York, An, et al., 2017). However, the management intention of jungle cleaning and the application and ecological efficacy of the technique is not well documented or explored in other studies.

Adaptive approach. We designed a financially feasible (low-cost) community-based management strategy to remove only invasive plant species. This approach was more meticulous than traditional jungle cleaning as it required a coordinated practice of invasive plant removal. In contrast with the traditional method, the adaptive method prioritizes the removal of only invasive plants and was hypothesized to be better suited to the ecology of the system and for the control of invasive plants (Chapter 2).

Prescribed fire. According to the forest management survey from 2014, prescribed fire is prevalent across the 21 CFs. However, setting intentional fires is not permitted in the CFs. Nonetheless, prescribed fire application is an existing forest management practice within the national park and CFs (Pokharel & Suvedi, 2007; L. M. Sapkota, Shrestha, Jourdain, &

Shivakoti, 2015). Prescribed fires were set under the supervision of a local forest guard or CF committee member in a manner that mirrored how local people would normally set fires in the dry, winter season. Fires burned at a low intensity and were set around the plots using accumulated leaf litter from the forest floor.

Group interview sampling technique. In each CF, group interviews (also referred to as focus groups) were conducted to provide perspectives on invasive plant and forest management (Barriball & While, 1994; Longhurst, 2003). Group interviews were conducted in January and February of 2018, at least three months after the most recent mechanical treatments. All interviews began outside of the CF in an easily accessible meeting area and were approximately 45 to 100 minutes in duration. The interview questions were designed to ask more generally about forest management perceptions and then more specifically about the issues of plant invasions within forests only. We did not ask questions about trust in forest managers or management explicitly as this was not a main goal of this interview or study, though the issue of trust has been shown to be important to forest management (Sullivan, York, White, et al., 2017).

We purposively sampled interviewees so that diverse perspectives and relationships to the CF and resource use were explored; there was a 100% response rate (Mason, 2002; Robinson, 2014; Trost, 1986). We sought five separate categorial groups of interviewees based on their relationship to the intervention (non-participant or participant in at least one intervention) separated by their gender (woman or man) and their position (individual forest user or forest resource manager). Forest resource managers were not separated by gender because women infrequently hold management positions in this study area. Interviewees were identified through the intervention experiment, CF users, word-of-mouth by other interviewees, and CF manager or forest guard suggestions.

Categories of interview groups selected within each CF:

1. Women who participated in at least one management intervention (Women Participants)
2. Women who have never participated in a management intervention (Women Non-Participants)
3. Men who participated in at least one management intervention (Men Participants)
4. Men who have never participated in a management intervention (Men Non-Participants)
5. CF Managers (includes men and women). Forest managers were never intervention participants.

All the interviews were recorded using an audio recorder and a note-taker. Each interview was conducted with one Nepali-fluent interviewer, one Nepali-fluent note-taker, and one English-fluent notetaker. All notetakers and interviewers were familiar with the intervention experiment and were present or collected data for at least one management intervention. The interview teams conferred with each other and took additional descriptive and explanatory notes at the end of each group interview, including statements about the tone, key themes, or surprising comments in the interview (Miles and Huberman, 1994). Interviews were not completely translated but were partially transcribed in Nepali then English, and main themes were coded and analyzed (Bernard, 2011; Bernard & Bernard, 2012; Burnard, 1991; Strauss & Corbin, 1990). The groups interviews were considered exempt by IRB.

Description of interviewees. We interviewed five groups from each CF for a total of 25 interview groups that included 116 people (Table 3.2). There were 54 women interviewed (only one woman was present in the CF management committee group in one CF). In general, more men hold leadership positions so there was a gender imbalance in the CF management committee interview groups.

Most interviewees (79%), identified their occupation as farmers or day-laborers. Of the interviewees, 98% lived within a 20-minute walking distance to their CF and on average they spent 14.8 days per month (30 days) in the CF (Table 3.2). In total, 89% of the interviewees were CF members though all interviewees were CF users in some manner (e.g. collected resources in the CF by permit, visited, recreated, etc.). We tried to avoid sampling more than two individuals from the same household; however, because women often go to the forest together to collect resources, a few of the interviewees were relatives. We documented any interviewees who were related to other interview group participants. In two CFs, all men participants except for one individual, had left this region of Nepal to find jobs (due to the common occurrence of out-migration in Nepal) (Bohra & Massey, 2009). In these instances, the single intervention participant was interviewed alone.

Table 3.2. Summary statistics of interview group respondents. Each interview group category consists of five interviewed groups for a total of 25 groups. The number of interviewees in each group may differ. Two interview groups of men non-participants had only one interviewee.

Interview category		**----------Interviewees from each interview category (n=5) across all interview groups (N=25)----------**					
Position	Gender	Total number of interviewees	Range of Interviewees per category	CF members	Mean ± St. dev of age	Mean ± St. dev of days entered the forest (30-day month)	Mean of interventions participated (out of 3)
CF manager	All	26	4-8	26	51 ± 10.7	14 ± 10.5	0
Non-participants	Women	31	5-8	26	44 ± 15.5	14 ± 11.0	0
Participants	Women	22	3-7	19	36 ± 16.7	14 ± 9.7	2
Non-participants	Men	25	4-7	22	47 ± 13.7	15 ± 11.0	0
Participants	Men	12	1-4	11	42 ± 9.0	17 ± 11.9	2

Group interview strategy. We developed three interview strategies and collected field data from January to March 2018. We began all group interviews with a free listing technique to elicit concepts of invasive plant species and rationales of invasiveness. We then asked semi-structured interview questions regarding forest management objectives and responsibility. Finally, we visited the intervention plots within the forest and assessed management preferences using direct plot observations and plot ranking.

Free listing method. To determine what plants are considered invasive and whether rationales for defining invasiveness differ between gender (men and women), position (forest managers and users), and familiarity (participants or non-participants), we implemented an elicitation technique referred to as 'free listing.' We identified components of the semantic domain "invasive plants", by asking all group interviewees to name plants that they consider to be a nuisance, harmful, and/or impede their daily activities in the forest. We restricted our free listing prompt to only include plants that have a negative impact; however, we do not ask respondents to consider the nativity of the plant or whether it is increasing beyond its 'native' range. We chose to only emphasize the negative effect of some species because ambiguity around the concept of nativity is the dominant reason for disagreement among invasion scholars on defining "invasiveness" (Selge et al., 2011). We then asked forest users to give their rationale for why they chose each plant. We intentionally asked interviewees to exclude agricultural nuisance species that more commonly grow in farms or common land areas. In other words, we asked them to focus on problematic plants within the forest.

Free listing can be used as an exploratory method to determine the contents of a particular domain (items that can be grouped together because they are considered to be similar and the grouping structure is thought to be universally true and defined within social groups) (Bernard, 2011; Bernard & Bernard, 2012). By using this technique, we can compare how rationales for invasiveness and items (plants cited as invasive) may differ between distinct social groups. Free list surveys are one of the most used elicitation techniques (Borgatti, 1999). Within a free list, immediate recall of an item (invasive plant) suggests the item has greater salience in that domain because it is more psychologically prominent and culturally important (Quinlan, Quinlan, & Nolan, 2002; Trotter & Logan, 2019). Across social groups, the frequency by which a plant is listed also contributes to its salience in that domain (Borgatti, 1999). We calculated the mean list length (total number of plants listed by a group), the frequency of citation (the number of occurrences of each plant across groups), and the order the plant is most frequently listed (rank of the plant). Cognitive salience of each plant species is determined by combining the order and frequency of plant citation across lists (Smith, 1993). Thus, more prominent invasive plants will be cited more often and earlier (lower rank) in the list and will be represented by a higher salience value.

The salience index of each plant can be calculated by determining the rank and frequency of the plant within all lists. The salience index ranges from very low salience (value of 0) to very high salience (value of 1).We calculated the salience index based on the following equation (Borgatti, 1999; Smith & Borgatti, 1997):

$$\frac{\sum \frac{(\text{Length of list} - \text{Rank of item j in list} + 1)}{\text{Length of list}}}{\text{Number of lists in sample}}$$

Semi-structured group interview – objectives of forest management. We aimed to evaluate whether invasive plant control methods are included in forest users' and managers' objectives for forest management by conducting semi-structured interviews with each interview group, separately. We chose a semi-structured interview because this technique has been shown to facilitate discussions among group members that are guided by the interviewees to prompt more in-depth responses and to have the flexibility to ask further questions on the subject matter (Robinson, 2014). With interviewee permission and per IRB protocol, audio from group interviews were recorded. We analyzed data content to identify patterns across interview groups regarding the theme of interest: forest management (Patton, 2002; Strauss & Corbin, 1990). We generally asked 8 to 10 questions to each interview group relevant to our research questions: *what are the goals of forest management, how are invasive plants prioritized, and who is responsible for forest management?*

Direct plot observations - preference ranking. To assess preferences towards forest management practices, we visited the four intervention plots within each forest and asked interviewees to discuss and agree upon a ranking for each plot along with a rationale for why the rank was chosen. We used temporary ropes to demarcate the boundaries of the plots and asked interview groups to explore the area for a few minutes prior to beginning our survey. Interviewees who had participated in the experiment were not reminded of the plot treatments, but it is likely they could recall the treatment types by themselves. We varied the order that we visited each plot between CFs but visited plots in the same pattern within a CF.

We use this ranking method of the four possible plots to determine consensus of treatment preferences across interview groups. The ranks are ordinal measurements and provided ranking options are only within the given set (four treatment types) and none of the treatment plots can be given the same rank (i.e. result in a tie) within the interview groups. Interviewees were asked to discuss and then give a rationale for their ranking system, collectively. The most recent mechanical treatment (traditional or adaptive method) of the plots occurred three to four months prior to the field survey and the most recent prescribed fires had been applied in January 2016 (two years prior).

RESULTS

Free list – What plants are considered invasive? Prior to the initiation of this study, we had relatively little understanding of what plants are conceptualized as invasive and whether those species differ between forest users and managers in our study area. We hypothesized that men and women might conceptualize the species of invading plants differently, since women enter the forest more frequently but are less likely to play a role in decision-making and forest management than men (Chhetri, Johnsen, Konoshima, & Yoshimoto, 2013). On the other hand, forest managers might be more likely to define invasive plants as the same target plants that researchers identified in the adaptive method (the six most common invaders) because the CF managers were consulted about the objectives of the project prior to conducting research in those communities. Finally, we expected interviewees who are familiar with the intervention (participants) to reiterate the same list of species that forest researchers used to guide invasive plant removal during the interventions; thus, they would have a more constrained view of invasive plants than non-participants.

All interview groups (n=25). A total of 33 community-defined invasive plant species were recorded across all 25 group interviews. *Mikania* was ranked first in 68% of all 25 free lists and was the only species to be cited in 100% of the free lists (Appendix H). The next most frequently cited plant was *Chromolaena* (occurred in 64% of lists), *Ageratum spp.* ‘gandhe’

(52% of lists), and *Lantana camara* (36% of lists). *Ageratum conyzoides* and *Ageratum houstonianum* occurred in 24% of lists but *A. conyzoides* had a higher salience because it had a higher rank (cited earlier in the list) than *A. houstonianum*. Similarly, *A. conyzoides* has a higher salience than *Lantana* because of its earlier position within most lists. *Ageratum spp.* were listed by most groups (52%), but the groups did not specifically identify which of the two *Ageratum spp.* were considered invasive since the two species are typically only identified by their flower color (blue or white) in Nepali language (*nilo* or *seto gandhe*). Nearly half (45%) of all the plants mentioned were cited in only one of the 25 interview groups (Appendix H).

Interview categories (n=5). All interview groups were separated into one of five categories: women participants (5), women non-participants (5), men participants (5), men non-participants (5), and CF managers (includes men and women, all are non-participants; 5). Regardless of familiarity (participant or non-participant), men listed the least amount of plants (23 citations) that they considered to be invasive while women listed 30.5 plants. Participants had an average list length of 25 and non-participants had an average list length of 29 cited plants, while CF managers cited the most species with total list length of 31. Overall, the mean number of unique plant species cited was similar across all interview groups (n=5) from a range of 4.2 cited by men non-participants to 6.6 plants cited by women non-participants (Table 3.3). Non-participants, regardless of gender, cited the highest number of unique invasive plants (18 species). Meanwhile, women participants cited a total of 15 unique invasive plants and men participants cited 12.

Table 3.3. Interview category free list summaries. The five interview categories are separated by position (intervention participant, non-participant, and CF manager) and gender (women or men). The list length indicates the total number of plants cited (some species could be repeated) across the interview category. The total number of species cited and summary statistics (mean, standard deviation, and range) are provided for the amount of individual species (not repeated) within each interview category.

Interview group category				Unique plant species cited				
Position	Gender	Number of groups	Total list length	Total # species cited	Mean	St. dev.	Min.	Max.
Community forest manager	All	5	31	16	6.2	2.4	3	9
Non-participants	Women	5	33	18	6.6	2.9	3	10
Participants	Women	5	28	15	5.6	1.1	4	7
Non-participants	Men	5	25	18	5.0	0.7	4	6
Participants	Men	5	21	12	4.2	0.4	4	5
Total		25	138	33	5.5	1.0	3	10

Some plants were only cited within specific groups by gender, position (user or manager), and familiarity (participant or non-participant) (Figure 3.2). The following seven plants were present in all interview categories (n=5): *Mikania micrantha*, *Ageratum conyzoides*, *Ageratum houstonianum*, *Urtica dioica*, *Chromolaena odorata*, *Lantana camara*, and *Ageratum spp.* (two species identified as just 'gandhe' in Nepali language) (Appendix I). As expected, some plants were shared between forest users but were not mentioned by the CF manager groups. For example, *Cirsium arvense* and *Solanum aculeatissimum* were mentioned by both men and women forest users but not CF managers. On the other hand, CF managers identified three species that were not mentioned by forest users; however, these three species were only cited by one of the five interviewed CF manager groups (Appendix I). Notably, the highly invasive non-native species included in the list of target invasive plant species, *Parthenium hysterophorus*, was cited by both women and CF managers but not by men regardless of whether they participated in the intervention or not. Further, *Ziziphus nummularia,* a thorny and pervasive native shrub was cited by men and CF managers but never by women.

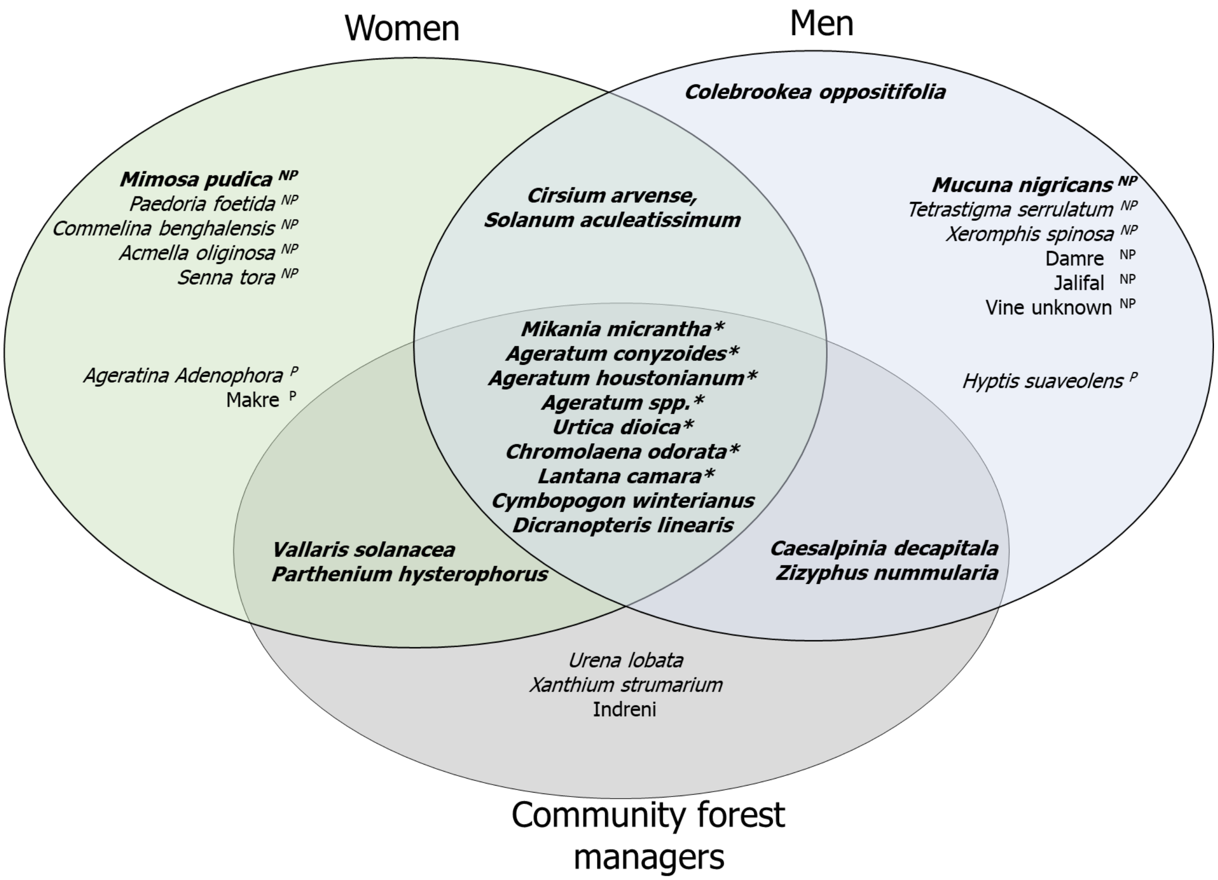

Figure 3.2. Venn-diagram illustrates the 33 unique plant species that were cited as invasive by community forest users (participants and non-participants), women (green), men (blue) and community forest managers (gray). Lighter colored text indicates the plant was cited in only one interview group (out of 25). The asterisks * indicate the plant was present in all 5 interview categories. Within the categories of women and men, plants that were only cited by non-participants or participants exclusively are marked by the superscript NP or P, respectively. If the scientific name of the plant was unknown, then we included the Nepali name in non-italicized font.

Of the 33 plants, 18 were cited in more than two interview groups. Of the more commonly cited plants, two were cited by just men (participants and non-participants): *Colebrookea oppositifolia* and *Mucuna nigricans* (Appendix I). Surprisingly, the majority of women non-participant groups (60%) mentioned *Mimosa pudica*, a low-growing legume known for folding its leaves in response to physical stimuli, but no other groups cited this species (Fondeville, Borthwick, & Hendricks, 1966). Forest users who had familiarity with the intervention (participants) listed fewer invasive species (Table 3.3) and the species they listed more often included the plants that researchers highlighted as the target plants for removal when implementing the adaptive approach (Appendix I).

Free listing. What rationales are given for why invasive plants were selected? We hypothesized that the roles social groups play in forest management, as approximated by intervention familiarity, position, and gender, could result in differing conceptualizations of why a plant is considered harmful and invasive. All interview groups, forest users, and managers, provided 15 specific rationales to address why they included a plant in their free lists. We collapsed the specific rationales into four main higher order themes: harm, utility, physical structure, and pollution. Given the free list prompt, the rationale that invasive plants cause harm was the most frequently cited across all groups regardless of familiarity with the intervention, position, or gender, as expected. In particular, women participants cited the rationale that invasive plants cause harm in 78% of the species they reported, whereas men participants cited this rationale for less than half of their plant lists. Further, the specific rationale that invasive plants harm other plants was the most common justification provided (55.8% of overall mentions) (Table 3.4). All interview categories mentioned the harm invasive plants cause to domesticated animals or wildlife, but women participants mentioned this rationale in only 3.6% of citations, whereas women non-participants and CF managers cite this rationale greater than 25% of the time (Table 3.4). Women non-participants were the only group to mention that forest invasive plants also caused harm to agriculture. Further, men were the only group to note that invasive plants impede sight or provide a hiding place for wild animals. Men participants were the only group to provide the rationale that invasive plants make the forest unclean or ‘dirty’ (9.5% of citations). Intervention participants, regardless of gender, cited the bushy or physical structure of the plant as a reason for its invasiveness three times more often than non-participants (Table 3.4). It was surprising to find that plant utility, as it relates to humans and animals, was one of the more common rationales (57% of citations overall) provided for why a plant is considered harmful. In contrast, 13% of all free list items were mentioned to have some actual use or the potential to be useful (Table 3.4). Notably, all groups except women participants suggested that invasive plants may have a use (typically as fodder, medicine, or food). Thus, our hypothesis that rationales differ between social groups was somewhat supported because participants are more likely to cite the structure of plant species (e.g. ‘bushy’) more than non-participants, but men and women generally conceptualize invasive plants as those that are harmful or have no use.

Table 3.4. Content analysis of all rationales given for what characteristics of the plant contribute to its invasiveness. Percent frequency of each rationale mention is calculated by dividing the total number of mentions by the total list length (number of items cited) per group. The rationales are organized from most to least mentions within their main theme.

			% frequency of rationale mentions within each interview category					
			Overall	CF mangers	Not participant		Participant	
Main theme	Specific rationale	Total # of mentions			Women	Men	Women	Men
			(out of 138)	(out of 31)	(out of 33)	(out of 25)	(out of 28)	(out of 21)
Harm	Causes harm to plants (other than trees) / prevents growth	77	55.8	51.6	48.5	52.0	78.6	47.6
	Causes harm to or kills animals	25	18.1	29.0	27.3	12.0	3.6	14.3
	Causes harm to forest	24	17.4	12.9	18.2	24.0	7.1	28.6
	Causes harm to humans	19	13.8	12.9	24.2	20.0	0.0	9.5
	Causes harm to agriculture	4	2.9	0.0	12.1	0.0	0.0	0.0
Utility	Not useful for humans or not eaten by animals	57	41.3	35.5	39.4	40.0	53.6	38.1
	Has some other use/ may be useful	13	9.4	16.1	12.1	8.0	0.0	9.5
	Not useful for animal habitat	1	0.7	3.2	0.0	0.0	0.0	0.0
Physical structure	Bushy structure	33	23.9	12.9	12.1	12.0	46.4	42.9
	Thorny	9	6.5	3.2	15.2	8.0	0.0	4.8
	Covers a large area / sprawling	9	6.5	6.5	12.1	0.0	7.1	4.8
	Difficult to remove	6	4.3	9.7	9.1	0.0	0.0	0.0
	Impedes sight / hiding place for animals	6	4.3	0.0	0.0	0.0	7.1	19.0
Pollution	Makes forest dirty / not clean	2	1.4	0.0	0.0	0.0	0.0	9.5
	Smells bad / air pollution	1	0.7	0.0	3.0	0.0	0.0	0.0

Objectives of community forest management activities - What are the goals of jungle cleaning? Prior to initiating the semi-structured interviews, we were aware that jungle cleaning was a commonly used approach for forest management in CFs; however, we were unsure to what extent this technique was employed and we were not sure if it was applied with similar intended ecological, social, or economic outcomes. Forest users and land managers referenced jungle cleaning by linking it to two main concepts: the removal of useless plants with the intention that useful plants will grow and to remove bushy or larger plants to increase visibility in the forest, especially from wildlife. Regarding jungle cleaning, one woman non-participant group noted that “Cleaning would be good for big plants, big plants will get fertilizer. We can see animals easily after cutting bushes.” When referring to ‘big plants’ forest users did not specify growth forms (trees, shrubs, herbs, or grasses) but based on the context of other responses, we inferred that bushy plants are considered harmful species as they impede the growth of other plants and they decrease visibility of wild animals. In many instances, bushy plants were held in a similar regard as harmful plant species or the term ‘bushy’ was used synonymously with the term ‘harmful’. Forest users and managers emphasized the idea that bushy plants suppress the growth of trees and small plants and maintenance of the bushy plants is required to support new growth in the forest. Similarly, the ideals for forest management were often described as a continuous growth and renewal of new vegetation by removing or thinning the current vegetation. In all instances, when we asked about forest management, the common sentiment was that people (forest managers, consumers, and forest users) manipulate the structure and composition of forest plants to increase useful plants, decrease harmful plants, sustain forest resources, remove garbage, and to increase safety from wildlife. We provide examples of each of these sentiments towards jungle cleaning objectives in the following sections.

Plant productivity. Most respondents suggested that the forest plants needed to be trimmed or that the removal of thick or dense plants will stimulate the production of new plants. For example, if bushy or harmful plants were removed, then they would act as a stimulant (fertilizer) for small plants to grow. One men non-participant group noted that “small plants will grow and the bush, which was cut, will be fertilizer.” This emphasizes the idea that not only are ‘bushy’ plants undesirable, but they should be targeted for removal as a means of stimulating the production of other small plants, which are desirable. All five interview categories (but not all 25 groups) made at least one reference to the removal of bushes as a way to promote the growth of small plants. Similarly, three of five CF management committees referenced the removal of bushy plants as a main objective of forest management (jungle cleaning).

Safety from wildlife. Of the 25 interviews, 9 groups referenced jungle cleaning as a means of staying safe from animals. Respondents talked about the need to reduce sight impediments, like large plants and bushes. Women interview groups in CF 1 often noted that they knew of friends or family members that had been wounded or killed from an animal attack. Markedly, during the women non-participant interview in CF 1, we witnessed a woman being carried across the river from the national park because she was attacked by a rhino while collecting grass. In other forests, women would note that we needed to move through the plots quickly and they did not want to linger in any one area for fear of animal attacks while we were conducting the interviews. Further, two women noted that they did not realize we were entering the forest and did not like to be dressed in red out of concern for attracting wild animals. Thus, it became clear that safety from wildlife is of high importance and is often considered when determining where to collect resources and how to manage the forest. The physical structure of the forest as it relates to the amount of 'bushes,' as an area for animals to hide or as visual impediment to monitoring for wildlife, was a key factor in forest management objectives in each of the five interview groups.

Forest resource sustainability. All respondents noted that jungle cleaning either removed useless or harmful plants or promoted the growth of useful plants. Forest users and CF managers emphasized the importance of 'saving' good plants or plants that are useful as important outcomes for jungle cleaning. Respondents referenced the future or the importance of sustaining resources by discouraging the growth of plants that had no use or that harmed the forest. Further, the stem density, often described as the 'thickness,' of plants was mentioned as a reason for cutting or removing vegetation. Managers and some forest users suggested that they had done jungle cleaning before (in *Falgun,* which is roughly the months of February and March) or in previous months but that one year or more had passed – often implying that there needed to be continuity in the timeline for forest management by avoiding flowering seasons or repeating jungle cleaning. Thus, jungle cleaning is often considered an active process of removal and reduction of forest vegetation rather than a single-application or stand-alone event.

Garbage removal / fence maintenance. It should be noted that the removal of garbage, paper, and plastic are also considered jungle cleaning. However, the removal of garbage was never the primary or only reason for conducting cleaning. Most references to jungle cleaning were concerning the removal of vegetation and not trash or debris. In addition, forest users mentioned that by keeping the forest clean and the fence mended and maintained, animals would stay in the forest and away from their farms, as crop raiding by wild animals in areas surrounding the CF is a common issue in this region of Nepal.

Who is responsible for forest management? In this set of questions, we asked forest managers and users what the objectives of forest management were in their CF and to identify who is responsible for managing the CF. Of the 25 interviews, 21 stated explicitly that the CF managers are responsible for forest management and of those interviews, 38% of groups stated that consumers (anyone who uses the forest) are also responsible for forest management or play a supporting role by doing what is asked of them by the managers. Notably, at least one interview group from each category (n=5) stated that CF users and managers played a role in forest management together. However, when considering responses within CFs, CF 2 was the only forest where all groups stated that CF management committees were exclusively responsible for management and never referenced consumers or villagers as playing a role in forest management.

When we questioned what the objectives of forest management were, 44% of forest users and managers responded that maintaining resources (grass, fodder, thatch, and firewood) for local use as well as protecting from natural disasters (particularly flooding and landslides) were the main objectives for forest management. It should be noted that the rivers that border Chitwan (particularly the Rapti river) flooded intensely in the monsoon season of 2017, five months prior to the interviews. These floods devastated rural communities around Nepal and left many thousands displaced or homeless (United Nations Office of the Resident Coordinator, 2017).

Direct plot observations – which intervention management approaches are preferred and why? In a previous paper (Chapter 2), we explored the ecological effect of intervention strategies on invasive plant abundance and found that overall, invasive plants respond to both the traditional and adaptive method negatively yet the effect is often seasonal and the total cover of invasive plants returns to the baseline amount after the growing season (monsoon season) each year. However, when assessed immediately (prior to the next growing season) after an intervention event, there are structural and compositional differences of the plants within the different treatment plots but there was not statistically significant ecological evidence to prove that there are differences in re-growth of invasive plants between adaptive and traditional treatments. Yet, we found that most forest users, regardless of their participation in the management interventions or their gender, were more likely to rank plots that had undergone the adaptive method as more preferable than plots that had undergone the traditional jungle cleaning method. Overall, adaptive plots were preferred over the traditional plots (Table 3.5). However, women who were not familiar with the intervention (non-participants), ranked traditional plots as their preferred management result over adaptive plots. This was largely due to the ranking of the plots in CF 2, where the mean rank (1 ± 0) of traditional plots was lower (more preferred) than the adaptive method plots by all interview groups within that forest (Figure 3.3). Further, in CF 1, most interview groups preferred the traditional unburned plots (mean rank 1.6 ± 1.3) over the adaptive plots, though there was not unanimity across all interview groups, as there was in CF 2. Other studies have shown that the 'Hawthorne effect', the propensity for respondents to change their behavior when they notice they are being observed, is a factor to consider when assessing treatment response (Mayo, 2004; McCarney et al., 2007). In our study, respondents documented both positive and negative sentiments about each plot, were not informed about the treatment type they were observing, and both participants and non-participants agreed on their ranking of the treatment plots. Thus, we presume that the respondents were unlikely to have experienced the Hawthorne effect.

Table 3.5. Overall preference ranking of each treatment plot across all interview groups (n=25).

Treatment type	Mean rank	SD rank	Overall rank
Adaptive - Burn	2.0	0.8	1.0
Adaptive - No burn	2.3	0.9	2.0
Traditional - Burn	2.7	1.2	3.0
Traditional - No burn	3.0	1.3	4.0

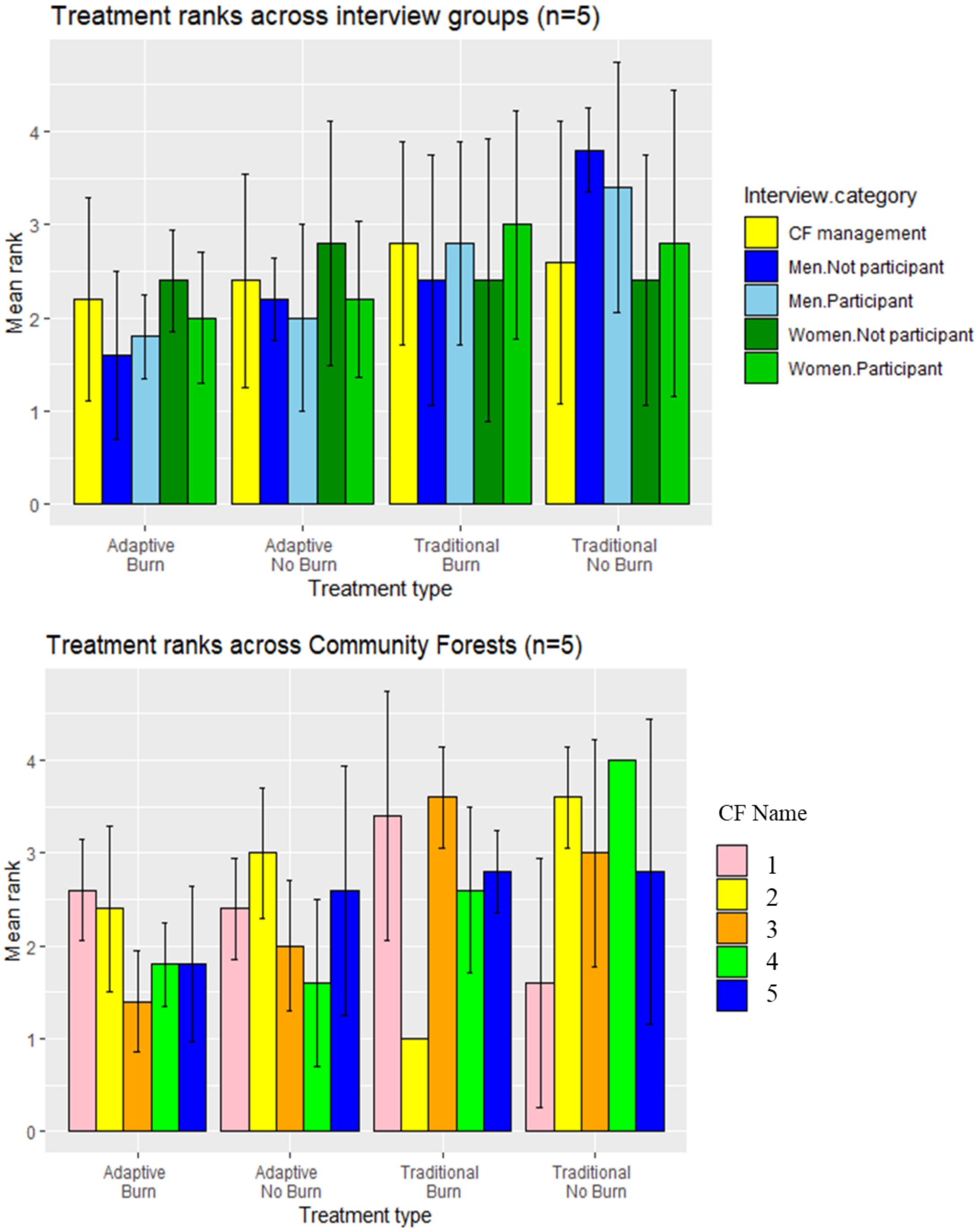

Figure 3.3. Mean ranks of each treatment within each interview category (n=5; top graph) and within each community forest (n=5; bottom graph). Standard error bars are in black.

Plot preference rationales. We explored the rationales given by each interview group to evaluate why management approaches are ranked from most to least preferred. Each treatment plot (four per CF) was given a ranking and rationale by each interview group (five groups) within that CF (five CFs) for a total of 100 rationales. Across all interview groups, there were 24 specific rationales given which were encompassed within seven higher order themes (Figure 3.4). These themes incorporated preference dichotomies. For example, the rationale for a preferred plot could be the abundance of resources while the rationale for a less preferred / undesirable plot could be a lack of resources; consequently, we coded those rationales under the theme "Resource availability" (Table 3.6). Some specific rationales described the locality (using terms like space, place, or area) of the plot as a whole and included terms that described the physical or visual landscape of the area: "empty", "clean", "clear", "nothing", "thick", and "dense". We coded these as representing the "Aesthetic" of the plot, but the terms have differing underlying meanings. For example, clean plots are rated as most preferred, whereas "empty" plots indicate a lack of resources and ranked among the least preferred plots. Rationales that specified the physical properties of individual plants (e.g. thorny, bushy, less bushy) were coded as "Plant structure" whereas rationales that indicated the potential or current environment as a whole (animals *will* or *will not* visit the plot, cool environment) were coded as "Habitat".

The theme "Plant productivity" was given for rationales that included the presence, new growth, height, or absence of plants. Within the theme "Plant productivity" we included the rationale "green" as forest users and managers implied that green represents both the presence and the health of those plants *and* interviewees often used the word green in conjunction with plants. Plant productivity and resource availability themes differed, as the productivity of plants did not refer to whether the respondent used or relied upon them as a resource. For example, a respondent may have referred to the extensive growth and productivity of an undesirable plant in the plot.

Table 3.6. Preference rank rationales. Specific rationales were categorized into seven higher order themes that generalize the content of the rationale.

Higher order theme	Mentions	Specific rationale	Overall mentions
Harmful plants	79	Absence (or less) harmful plants	45
		Presence of harmful plants	34
Resource availability	38	Resources are available	24
		Resources are less or unavailable	10
		Presence of useless plants	4
Plant productivity	23	Absence (or less) plants	9
		New growth	5
		No green or less green	3
		Big trees or grass	3
		Green	2
		No small plants or no new growth	1
Aesthetic	18	Open area	8
		Clean area	6
		Empty	1
		Clear	1
		Nothing	1
		Thick or Dense	1
Structure of plants	12	Absence (or less) bushes	5
		Bushy	5
		Thorny	2
Habitat	5	Cool (temperature)	2
		Animals will visit	2
		Animals will not visit	1
Fear	1	Not scared of animals	1

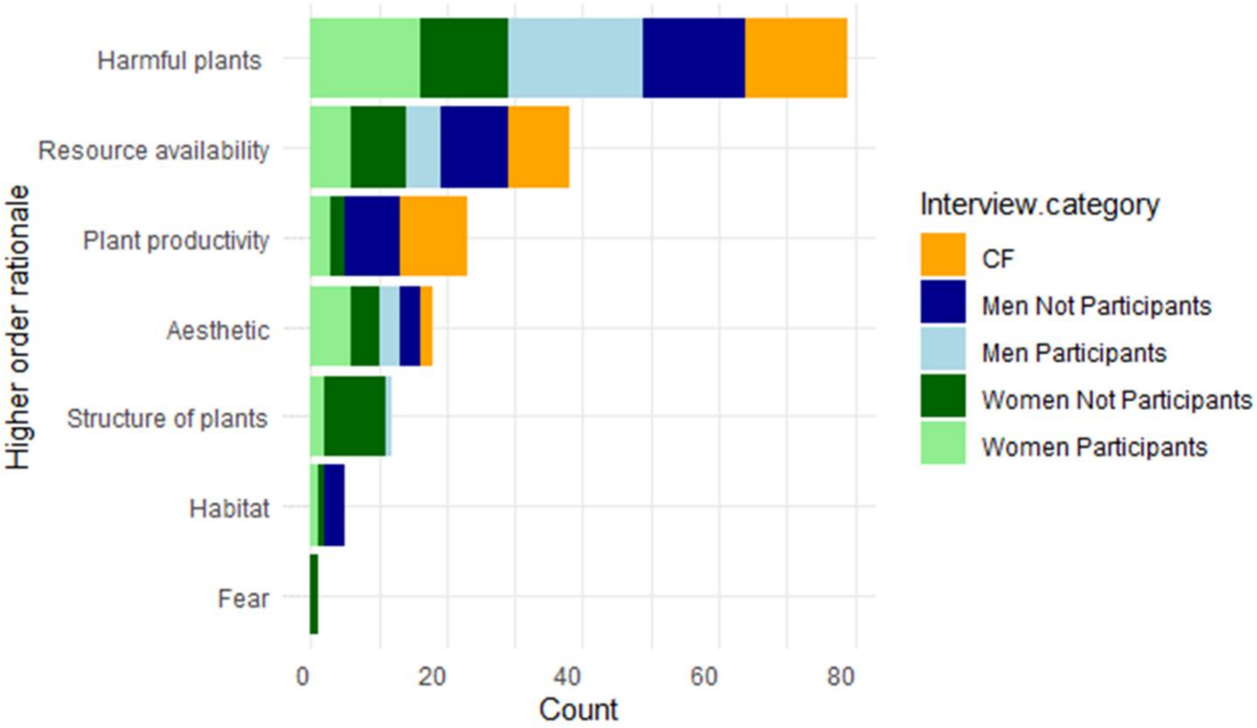

Figure 3.4. Overall counts (out of 80) of each rationale given to describe treatment plots within interview categories.

Presence or absence of harmful plants was categorized under the theme "Harmful plants". The following plants were directly cited as harmful during the plot ranking: *Chromolaena odorata*, *Urtica dioica*, *Ageratum spp.*, *Mikania micrantha*, and *Solanum aculeatissimum*. These plants were mentioned as the interview groups were observing the plots and were addressing the properties of the species around them. There was one rarely cited rationale, "not scared of animals" which we place in the category "fear" as this rationale was based on emotion and unique from other themes regarding utility or physical properties of the plots.

DISCUSSION

We assessed the following aspects of land management interventions as they relate to invasive species: 1) perceptions of invasive species: identification and rationale of species invasiveness; 2) forest management preferences across social groups – positions of power (land manager and land user), familiarity (participant or non-participant in experimental intervention practices), and gender; 3) intentions of existing (traditional) management approaches. These three aspects of management are explored as separate sections below.

Perceptions of invasive species - Identification of invasive plant species. We hypothesized that because women enter the forest more frequently and have a more intimate relationship with resource collection, they are likely to conceptualize or view invasive plants differently from men. We expected that intervention participants would define fewer species as invasive and their invasive list would reiterate the list of invasive plants identified in the adaptive method for removal. Additionally, we predicted their view of invasive plants would be constrained by how the researchers framed the intention of the intervention – to remove the six dominant invading plants. Surprisingly, we found that, overall, there are seven individual species that are consistently considered invasive across all five interview groups. Further, when considering the six plants we were targeting for removal in the intervention (bolded plants in Appendix I), five were cited as invasive in all interview categories, suggesting that forest user intervention participants have similar concepts of invasive plants as forest users who were unfamiliar with the intervention project and, in general, dominant invaders are the same regardless of gender and position (forest manager or user).

Thus, the six main invading species that we aimed to manage in the intervention project are also reflected as being invasive species by the land users and managers. However, *P. hysterophorus*, one of the target invasive plants, was notably absent from free lists reported by men, regardless of their role in the intervention. As this is a relatively new and less abundant invasive plant, we suppose that women, who enter the forest far more frequently than men, were more likely to notice this uncommon invasive plant. Further, *P. hysterophorus* exudes an irritant that causes skin rash, so it might have been noticed more by women who are more likely to collect grass and fodder than men. It was not surprising that even men who participated in the intervention (and therefore were familiar with the six common invaders) also did not mention *P. hysterophorus*, because men participants often occupied a different role in the intervention application than women (men were digging the hole for plant disposal rather than identifying and removing invasive plants).

Not only did women forest users cite a more recent and less abundant invasive plant, *Parthenium*, one interview group (women participants) cited another highly prolific invader in Nepal, *Ageratina adenophora*. We did not account for this invasive plant in our list of target invaders because it was not detected in our 2013-2015 ecological surveys; however, the introduction of *Ageratina* in other regions of Nepal and around the world has resulted in ecological challenges and economic losses (Poudel, Jha, Shrestha, & Muniappan, 2019). We assume that because women are more likely to visit the forest and to engage with plant resources, they are more aware of immediate ecological shifts within their CFs than men (who typically enter the forest less frequently).

Invasive plants are especially challenging to detect because they are less visible forms of environmental transformation relative to large-scale natural disasters or rapid ecological declines (Balding & Williams, 2016; Miller & Gunderson, 2003; Sanders, 2019). Studies have shown that perceived vulnerability of environmental risks differ between gender, where men are far less likely to perceive risks of environmental challenges than women (Bord & O’Connor, 1997).

Similarly, this study finds that in many ways, women are acting as “canaries in the coal mine” for invasive species detection and are observing novel species invasions earlier than men.

Rationale of species invasiveness. We hypothesized that some social groups (women and men, or land manager and forest user) may differ in how they rationalize why a species is considered harmful or invasive. Differences between the roles that forest users play in collecting resources and how domestic groups are constructed was founded within the concept of modes of production, specifically, how households directly acquire resources and differentiate production of labor between groups (Godelier, 1975). For example, groups are socially organized so that some members are contributing to resource use and collection in specific ways. In the context of this study area, women are often assigned a role in their social group as the dominant resource collectors for their household while men are given or are elected to more decision-making roles (Agrawal 2001). Differences in labor division between genders can influence patterns of forest use dynamics, and forest user relationships to resources may in turn alter their knowledge and perceptions. Given that the social construction of domestic groups plays a role in resource management, we found that there are some differences between the lists of invasive plant species in distinct social groups (gender, participation, and position). However, the overall rationale for why a plant is invasive was relatively uniform across groups and was primarily related to how the plant influences the growth and productivity of other plants, the utility (or lack thereof), and the physical and spatial structure of the plant (often regarded as an impediment for human use or as a space where wildlife could hide). In many ways, this definition does align with the invasion biologists use of the term ‘invasive,’ however, the notable difference was related to the utility of the plant. Plant utility (or lack of utility) has not been given as biological reason for its invasiveness in other contexts (Colautti & MacIsaac, 2004; Pejchar & Mooney, 2009). As many forest users noted, an abundance of 'useless' plants in the forest could contribute to further invasion of a site and negative impacts on surrounding vegetation and human livelihoods; thus their rationale regarding plant utility alludes to the biological process of invasion and the social impact of invasive species. Since the rational, 'utility,' was particularly commonly cited by women, the dominant forest user, it is especially important to consider that the amount of useful or useless plants present in the forest (or management plots) could alter preferences for invasive management control techniques.

Forest management preferences. Forest users and managers in our study area expressed that they preferred adaptive management approaches over the traditional management plots, even though they were not informed about the management style prior to visually observing the plots. Surprisingly, there were few statistically significant ecological differences detected between the two mechanical treatments, yet most forest users and managers preferred adaptive management plots (Chapter 2). Notably, CF 2 was the only CF where interview groups never mentioned a collective (e.g. consumer, forest user, or villager) role in forest management. At the same time, this was the only CF to also rank the traditional method unanimously as being more preferable than the adaptive approach. While CF 2 managers and users differed from other CF interview group plot preferences, they gave the same rationale for this preference: an abundance of forest resources. Anecdotally, CF users in this forest were the least enthusiastic or interested in conducting the intervention treatments.

When considering gender dynamics, it is important to note that few men intervention participants were available to be interviewed. This is because in two of the CFs, most of the men had already migrated out of Chitwan to find work outside of the community, a common occurrence in Nepal (Bohra & Massey, 2009). Meanwhile, most women are tied to their households and are far less likely to seek employment through out-migration. Thus, not only are women more likely to collect resources, visit the forest, and detect novel plant invasions, they are also more likely to stay in those communities longer than men. For this reason, women should inherently have a stronger capacity than men to make local-level changes in forest management, however they have been historically disenfranchised in local-level politics and decision-making processes (Agarwal, 2010; Chhetri et al., 2013; Elias, Hummel, Basnett, & Colfer, 2017).

Intended effect of existing (traditional management). Prior to the initiation of this study, we were unsure how forest users and managers perceived the efficacy of their current management approaches and whether the “jungle cleaning” method was being applied towards the management of invasive plant species. We found that the most common goals of jungle cleaning were to improve safety from wildlife, enhance plant productivity and resource sustainability, and to clear the forest of anything unwanted (objects like garbage or undesirable plant species). These same sentiments were expressed as a rationale for why forest users preferred adaptive management plots over the traditional method plots, indicating that these preference metrics are inherently important to forest users and mangers and should be a component of forest management activities in the future. For example, the removal of harmful plants was not unanimously considered the main goal of jungle cleaning, but it was mentioned in 79% of all intervention plots as reason for preferring or not preferring the plot – indicating that harmful plants should be prioritized in forest management plans for social reasons (considered harmful) and ecological reasons. Further, adaptive management practices were not only preferred by forest users and managers, they were also ecologically more likely to contribute to the long-term management of invasive plants (Chapter 2).

ACKNOWLEDGEMENTS

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CHAPTER 4

LOCAL PERCEPTIONS OF INVASIVE PLANTS: THE ROLE OF ETHNOECOLOGY IN COMMUNITY-BASED CONSERVATION STRATEGIES

ABSTRACT

The negative ecological impacts of invasive plant species are not always immediately visible and may be disregarded by local communities if social benefits of control efforts are not clear. Local stakeholders are key to effective invasive species management, but lack of understanding or buy-in could obstruct restoration activities and provoke social conflict. Furthermore, uninformed management actions could unintentionally disrupt local livelihoods by removing species that fill a resource need. Ethnoecological approaches that assess and incorporate the diverse perspectives of local people are thus critical to the long-term success of invasive species control activities.

Invasive plant species are spreading within working forests near protected areas worldwide, threatening endangered native species and the livelihoods of communities that depend on natural resources. We studied local people’s perceptions of invasive and native plants in community forests that surround Chitwan National Park, in the sub-tropical region of Nepal. We compared knowledge about and perceptions of forest plants among Nepali migrants (migrated internally from other regions of Nepal) and ethnically indigenous groups, using ethnoecological elicitation techniques. Conceptualizations of plant species differed significantly between men and women, and between migrants and indigenous individuals, highlighting the importance of investigating different social groups to fully characterize community perceptions. Women considered fewer plant species to be valuable to their lives or livelihoods than men, but both collected and used some invasive species. Counter to our hypothesis, indigenous people identified fewer plant species as valuable to their livelihoods than did internal migrant groups. Surprisingly, we found that almost half the surveyed respondents use at least one invasive plant for some purpose, though few people identified invasive plant species as important to their lives. Finally, we found that study participants from all groups perceived invasive plants to be low-risk phenomena relative to other environmental problems, which could deter local users from engaging in invasive species management solutions in the future. Results from this study can help land managers improve forest management and restoration plans by considering the cultural relevance and utility of invasive and native plants, and gauging stakeholder interest or prioritization of invasive species.

INTRODUCTION

Restoration ecologists and land managers have the difficult task of recovering ecological processes or properties lost from environmental damage, mismanagement, or the arrival of novel perturbances. Ecological sciences have historically focused on solving environmental problems in a framework that excludes social perceptions and local knowledge about systems management (Bradshaw & Bekoff, 2001; van Andel & Aronson, 2012). However, the persistence of environmental challenges within inherently interconnected social-ecological systems is highlighting the need to find management practices that are socially acceptable and that minimize conflicts between land management goals and social values (Crowley et al., 2017a; Estévez et al., 2015; Ives & Kendal, 2014).

One such environmental challenge is the invasion of non-native, harmful species. Species invasions, the accidental or intentional introduction of species that cause ecological, economic or social harm, are considered to be the second leading threat to biological diversity worldwide, behind habitat loss (Elton, 2000; Paini et al., 2016; Pimentel, Lach, Zuniga, & Morrison, 2000). Despite the negative environmental consequences of invasive species, stakeholders, land managers, and scientists often hold diverse, sometimes opposing views on the benefits and cultural significance of invasive species (Bardsley & Edwards-Jones, 2007; Selge et al., 2011). These heterogeneous views could arise from evolving perceptions of what belongs or does not belong in the environment (e.g. what is considered native and not native) and unique personal or cultural values that shape the way we perceive landscapes (Nazarea, 1999). If not considered prior to implementing management plans, different attitudes and perceptions towards invasive species among stakeholder and social groups could hinder the achievement of management goals or the implementation of management activities (Selge et al., 2011; Selge & Fischer, 2011).

In order to emphasize, rather than overlook, the social mechanisms that could inform management and restoration practices, the concept of adaptive management has arisen as a means of managing ecosystems sustainably (Aronson, Pereira, & Pausas, 2012; Berkes, Colding, & Folke, 2000; Berkes, Folke, & Gadgil, 1994; Berkes & Turner, 2006; Palmer, Zedler, & Falk, 2016). Adaptive management often embraces alternative knowledge systems to inform restoration goals, mainly in areas where local people receive benefits directly from the environment (Berkes et al., 2000). One type of alternative knowledge system held by indigenous and local peoples, Traditional Ecological Knowledge (TEK), evolves from long-term observations by people of ecosystem processes and outcomes from natural and anthropogenic perturbations (Usher, 2000). Studies have shown that adaptive management plans that include the human dimension through traditional practices, TEK, community perspectives, or livelihood assets and constraints are imperative to advancing the goals of ecological restoration, especially in the context of plant species invasions, one of the greatest environmental challenges of the 21st century (Palmer et al., 2016). To date, restoration science has primarily tackled the issue of species invasions through management plans informed primarily by ecological data and modeling. Few studies have focused on methods to overcome the social barriers that repeatedly appear when implementing management plans. For land management programs to confront the challenge of invasive species holistically, plans that incorporate the different values and perceptions of invasive species between stakeholders should be explored (García-Llorente et al. 2008).

In this study, we explore the people-plant relationship and the way that plants – both native and invasive – influence human lives and livelihoods among different social groups. Specifically, we identify the relative preferences and perceived utility of common native and invasive plants. This information can be used to inform forest management practices about the social and cultural values of plant species, especially for historically disenfranchised groups who wield less power in decision-making yet whose livelihoods are often most influenced by those management decisions.

Social implications for invasive plant management. Differing perceptions of invasive species, a lack of diverse stakeholder perspectives in management, and a paucity of scientific data in the regions that are most afflicted by species invasions (e.g. rural areas and developing nations), are often considered barriers to effective invasive species management (Pysek et al. 2008; Shackleton et al. 2019; Early et al. 2016). Because the ecological impacts of invasive species on ecosystems are not always immediately visible, perceptions of species invasion often differ among stakeholders (García-Llorente et al., 2011), and the harm caused may be disregarded if the invasive species provide a social benefit (García-Llorente et al., 2008). Individuals may have conflicting ideas about which plants are useful or desirable and which are pests. In some instances, invasive plants become embedded in cultural identity (e.g. tumbleweeds as a symbol of the a symbol of the American frontier, Young 1991), engrained in folklore (e.g. narratives of *Heracleum persicum* in Norway, Alm 2013), or positively contribute to the available pool of natural resources (e.g. cultural and economic value of invasive plants in Brazil, dos Santos et. al 2009, 2014). Invasive species are not universally perceived as a threat, and some may even wear a “cultural camouflage” because psychological and conceptual barriers prevent individuals, laws, and policies from acknowledging the harm they cause (Miller & Gunderson, 2003). When implementing actions, a lack of diverse perspectives among scientists and managers of invasive species can result in social conflicts with communities (Crowley et al., 2017a). Increasingly, studies have shown that incorporating cultural knowledge and local values into management decisions can be effective for conserving biodiversity and minimizing conflict (Bennett, 2016; Posey, 1992; Nazarea, 2006). But lack of a framework or methodology for assessing perceptions along with environmental properties can impede management plans (F Berkes, 1993).

A way forward: Restoration Ethnoecology. Ethnoecology is the study of how people manage, perceive, and interact with the environment through the domains of belief, knowledge, and practice (referred to as the kosmos, corpus, and praxis complex) (Barrera-Bassols & Zinck, 2003; Barrera-Bassols & Toledo, 2005; Manzur, 2013). Ethnoecological approaches are well-equipped to address many of the challenges of ecological restoration, yet disciplinary separations (e.g. journals, communications) have discouraged inclusion of ethnoecological methods into ecological publications and ecosystem management approaches. Incorporating the human perspective and identifying TEK content (what is known) and processes of acquiring knowledge (ways of knowing) are intrinsic to ethnoecology (Berkes, 2009), and draw from mixed methods of ethnographic surveys, botanical and ecological data collection, and documentation of environmental knowledge. Though ethnoecological approaches gather information on ecological processes and biotic interactions using the same nomenclature and taxonomic hierarchies as in the ecological sciences, the discipline itself is rooted in applied anthropology (Posey et al., 1984). In order to capture the complexity of worldviews held by local people, assessments of stakeholder perceptions on natural resource management should be conducted in a way that describes the diversity of knowledge, beliefs, and practices across the range of stakeholder social groups. Restoration ecology, similar to ethnoecology, is inherently rooted in human values(Hobbs et al., 2004; Palmer et al., 2016; Shackelford et al., 2013). Yet, the success of an applied restoration project is often measured by its ability to transition ecosystems from degraded to desirable environmental conditions, rather than the ability of that system to meet human needs (Higgs, 2005). By combining the practice of restoration ecology with the methodologies of ethnoecology, an integrated discipline emerges to address the needs of local people by adapting or adopting restoration practices in a way that incorporates multiple stakeholder perspectives, TEK, and values: Restoration Ethnoecology.

Restoration ethnoecology is especially important to apply in areas where the outcomes of ecological diversity intersect with culturally diversity and variable livelihood needs (Naveh, 2007; Pilgrim et al., 2009). Stakeholder social groups, made up of culturally diverse people, may occupy the same area but hold different beliefs about nature, TEK, and different knowledge relating to the environment and plant diversity. For example, Ghimire, McKey, and Aumeeruddy-Thomas (2004) found that two culturally distinct groups possessed different environmental practices and specialized knowledge about medicinal plant species even though they had lived in the same valley for generations and collected some of the same plants. In contrast, migrants into new areas may disregard sustainable resource-use practices or may be unaware of them, and instead they may respond to regional or economic incentives by increasing rates of harvesting or altering land use (Nesheim, Dhillion, & Anne Stølen, 2006). Migrants may also stimulate new practices and contribute their own TEK to the system, but motivations for migrant groups to act collectively (e.g. community identity and social cohesion) may differ from those of indigenous groups (Berkes, 2009). For example, indigenous groups tend to have a stronger place-based identity relative to their ancestral lands, so they may be more likely to consider sustainable land-management practices compared to migrant groups, who are less likely to have place-based identity (Williams, Stewart, & Kruger, 2013). Social groups may also show differences in worldviews based on gender. For example, men and women in the same environment might have different perspectives or knowledge about plant species and species invasion because the household natural-resource collection duties are partitioned in a way that genders domains of knowledge (Dan Guimbo, Mueller, & Larwanou, 2011).

In this study, we use integrated ecological and ethnobotanical surveys within the sub-tropical ecosystem of Nepal, an ecologically, linguistically, and culturally diverse region, to analyze how ethnicity and gender intersect to influence perceptions and knowledge of plants and how local people’s lives are shaped by invasive plant species. We focus on indigenous and internal migrant populations within Nepal to identify how cultural groups' knowledge and perceptions of invasive species may differ based on their relationship to the invaded region. Our analyses also consider how knowledge of plant utility and actual plant utility may differ (that is, knowing the possible use of plants versus actually using and relying upon those plants), not just between cultural groups but among genders as well. We investigated the following questions: 1) What plants (native or invasive) are important to people's lives and sustaining local livelihoods? 2) How do indigenous (autochthonous peoples) and migrant groups (internal migrants within Nepal) conceptualize invasive and native species? 3) What are the uses and preferences of different invasive and native species in these invaded systems? 4) How are invasive species ranked or compared to other environmental problems in this system? Finally, we provide insight into forest user perceptions of invasive plants – specifically the diversity of use and value of different plant species – and how this knowledge can inform future forest management plans.

Our study is situated within the buffer zone community forests of Western Chitwan Valley, Nepal. These forests are an important source of natural resources for the local community and border the country's first national park, an area of immense biological diversity and a source of national pride. Chitwan Valley is a prime location to study invasive species because the area has been invaded by fast-growing, non-native plants that are perceived nationally to cause harm to communities. Additionally, patterns of distribution and abundance of invasive plant species are well documented (Dangol & Maharjan, 2012; Joshi et al., 2005; Murphy et al., 2013; Rai, Scarborough, Subedi, & Lamichhane, 2012).

STUDY SITE CONTEXT AND HISTORY

Our study took place in the subtropical Terai region of Nepal. The Terai region was considered an inhospitable, mosquito-infested lowland until the eradication of malaria in the late 1950s (Ojha, 1983). Because of the density of malaria, few people other than the malaria-resistant indigenous group, referred to as the ‘Tharu,’ occupied the Terai. The Tharu were historically dependent on natural resources, often relying on shifting agriculture and fishing as livelihood strategies (Guneratne, 2016). The Kumal, Bote, and Darai are also considered indigenous to the Terai, but their populations were smaller than the Tharu (Müller-Böker, Stellrecht, & Winiger, 1997). Though they are ethnically distinct from Tharus, they often share traditions and communal living spaces in inter-connected, mud-bonded houses, and there are similarities among their mother tongues (Paudyal, 2008). These indigenous groups lived relatively free from colonization or foreign settlement until the 1950s, when the government sold parcels of land throughout the Terai, especially in the Chitwan Valley district, as a planned effort to encourage internal migrants (people from other regions of Nepal) to settle there.

Chitwan Valley underwent a major demographic shift as the population increased immensely after the centralized government initiated resettlement of the Hill population (referring to people from the geographic center of Nepal) to the lowlands (referring to the Terai) (Agergaard, 1999). Most internal migrants were Bhramin, Chhetri, Tamang, Gurung, and Newar farmers who moved to the Terai to acquire inexpensive, arable land. From the 1960s onward, land was rapidly converted to farmlands, and forests were severely degraded by over-harvesting timber (Chaudhary, 2000). Meanwhile, the Tharu and other indigenous groups remained landless and continued to rely on forest resources and riverways for their subsistence (Shrestha, 2019). Some landless Tharus entered a form of indentured servitude to the land-owning migrants (an exploitative practice that was not completely abolished until 2002) (Budhathoki, 2012; Giri, 2010). A secondary surge of internal migrants into the Chitwan Valley followed in the late 1970s, after the construction of a highway from Kathmandu, the capital city of Nepal, that connected Chitwan district to the East-West highway across Nepal (Bohra & Massey, 2009). This new wave of migrants settled Chitwan in search of business opportunities in the newly connected valley. The secondary wave of migration brought with them new businesses and more infrastructure, such as bus routes, schools, government services, and jobs. Thus, the economic and ethnic diversity of Chitwan Valley shifted rapidly between 1950 and 1975 (Müller-Böker, 2000). With this rapid shift, forests were over-harvested or converted to agriculture, shrinking the habitat for endangered species (Elder, 1976).

Recognizing the rapid decline in critically endangered species habitat, Nepal's government created the first national park of Nepal in 1973, near the southern border of Chitwan. However, the establishment of the national park forced indigenous groups out of the intact forest and further decreased their access to forest resources (McLean, 1999). The creation of national parks has often led to distrust and conflict between governments and those evicted from the protected area; Nepal is no exception (Mehta & Kellert, 1998). Displaced indigenous and migrant groups were left with few livelihood options and often harvested resources in the national park (Stræde & Helles, 2000). In response to illicit harvesting pressures within the national park and as a way to incentivize communities to change their harvesting activities and protect natural resources, the government created a buffer zone that would allow forest-users to regulate forest resources on their own (Straede & Treue, 2006). These buffer zones were established around the same time as the deregulation of forest resources in 1993, which stimulated the creation of community forests within the buffer zone (Nagendra, 2002). In each community forest (CF), local people elect individuals from their community to serve as management committee members. CF establishment in Nepal has been touted as one of the most successful bottom-up approaches to forest resource management (Kellert & Mehta, 2000). Since the construction of the CFs, forests have recovered and serve as a source of non-timber forest products and ecosystem services for the communities around the national park (Chaudhary, 2000; Oldekop, Holmes, Harris, & Evans, 2016; Oldekop et al., 2019).

Currently, 21 CFs are established in the Western Chitwan buffer zones of Chitwan National Park (Figure 4.1). These working forests are all locally governed with distinct rules about resource collection, and the communities surrounding the CFs have differing socio-economic dependence on forest resources. Communities that are more dependent upon forest resources are generally furthest from roads, bus routes, and market resources in the main city of Chitwan (Narayangarh, located approximately 21 km away) (Sapkota & Odén, 2008). These forest-dependent communities are a mix of internal migrants and indigenous groups. Most resource users enter the forest to collect edible and medicinal plants, fodder for domestic animals (mainly buffalo and goats), firewood, thatch (construction material for housing), and for recreation, religious, or ceremonial purposes (Chapter 1). Local livelihoods are intertwined with the nearby CFs, especially households with a subsistence-based dependence on forest resources. The transition to community-driven management from centralized management starting in 1993 allowed the forests to recover from severe degradation and tree species, especially timber, rebounded substantially. But ecological problems, like invasive species, are putting these forests at risk of degradation once again (Figure 4.2).

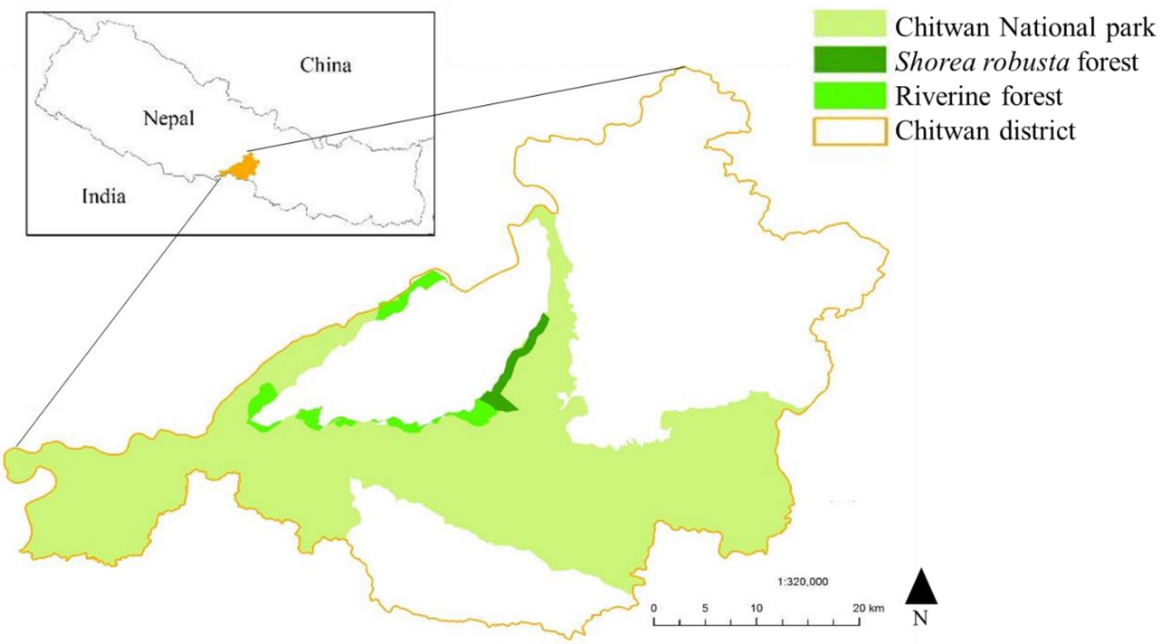

Figure 4.1. Buffer zone surrounding the protected Chitwan National Park in Nepal. The orange line delineates the entirety of Chitwan District while the light-green shaded area represents the entire buffer-zone of the national park. Within that buffer zone are two distinct forest types: *Shorea robusta* (Nepali name: Sal) and Riverine forest (a mixture of *Bombax ceiba* and *Dalbergia sissoo* trees; Nepali names: Simal and Sisau).

Figure 4.2. Distribution of Mikania. Map showing the distribution of one of the most prolific invasive plant species in Chitwan region, *Mikania micrantha*, with darker red indicating greater abundance. Top right: abandoned cattle shed covered by *Mikania*. Bottom right: image of characteristic opposite leaf arrangement (pair of deltoid leaves at each node) of *Mikania*.

Invasive plants are of concern in this region of Nepal because they cause ecological and economic damages, as well as harm to human health in areas that are already highly vulnerable to invasion (Foxcroft et al., 2013, 2017; Meiners & Pickett, 2013). *Mikania micrantha* is the invasive species of greatest concern in this region because it can quickly overgrow forest canopies and grassland species, like *Imperata cylindrica* and *Saccharum spontaneum* (Figure 4.2). Five other common invasive plants have been documented in the CFs across the Western Chitwan district (Chapter 1).

METHODS

Study area selection using ecological and household surveys. To assess local perceptions of invasive and native plants, we first determined the dominant invasive plant species, forest-user resource dependence, and common forest management practices within all 21 CFs to distinguish which were most influenced by invasive plants and had a high population of forest resource users. We explored household-level resource dependence and invasive species distribution and abundance using social and ecological plot surveys conducted between 2013 and 2015 (Chapter 1).

Methods for household surveys are described in detail in Chapter 1. Briefly, we surveyed households in 2014 throughout community-forest catchment areas in Chitwan Valley. In total, 1235 households were located sufficiently near a CF that they would be eligible to join or access the forest: additional household selection detail in Yabiku et. al 2017 and Chapter 1. We chose to restrict our study site to households and CFs (dominated by *Bombax ceiba*) nearest to the Rapti River on the southern border of western Chitwan, because this is where the average household reliance on forest resources is the greatest (relative to the northern, *Dalbergia sissoo* dominated riverine forests, and the eastern, *Shorea robusta* dominated forests). As a natural delineation to our study area, the Rapti River is the boundary separating Chitwan National Park and the buffer-zone CFs. Ecologically, this area has the greatest infestation of invasive species, particularly *Mikania micrantha* (Chapter 1). Economically, the CFs near the Rapti River are the furthest from the city center and have the lowest access to market resources (Figure 4.3).

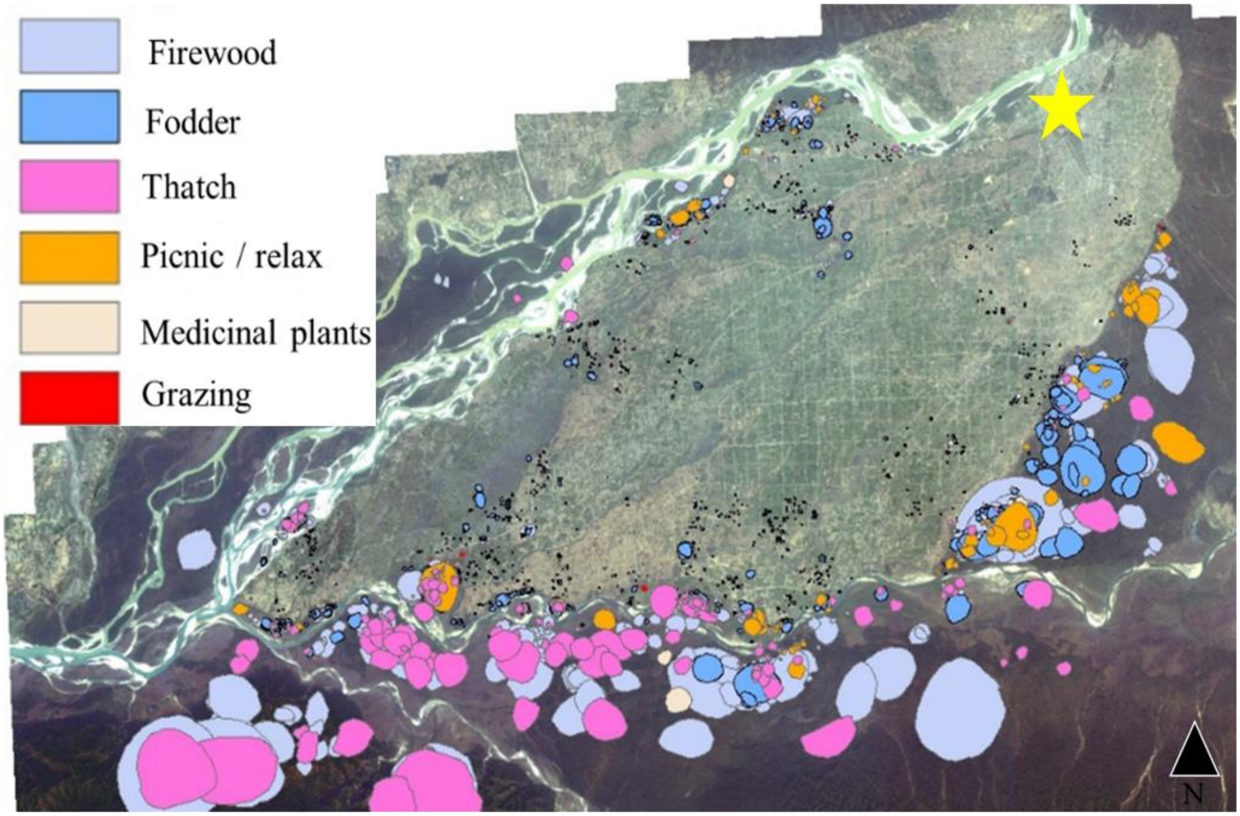

Figure 4.3. Surveyed resource collection data from 1235 households (survey details in Chapter 1). Using a zoomable tablet interface, respondents marked where on the map they conducted the following activities in the past year: firewood, fodder, thatch, and medicinal plant collection, picnicking / relaxing (leisure), and grazing. Most resource-collection activities occur in the forests that are distant from the city center (yellow star).

We performed an ecological survey (see survey details in Chapter 1), based on species abundance (percent cover) and determined the dominant invading plants (6 species) and 20 of the dominant native plant species in CFs that occur along the Rapti River. We then constructed a list of these 26 dominant invasive and native plant species, hereafter referred to as the reference plant list (Table 4.1). This plant species list included plants from all growth forms: trees, grasses, herbaceous (non-woody stems), and shrubs. We created 26 plant-placards that contained leaves, stems, and other identifying morphological features (i.e. flowers, trunk, fruits, etc.) of all native and invasive plants. After pressing and drying plants collected directly from the riverine CFs, we used standard herbarium specimen-preparation procedures to adhere the plants to cardboard along with a photo of their flowering part (as the plants were not in bloom at the time of collection). The dominant invading plant species included: *Mikania micrantha*, *Lantana camara*, *Chromolaena odorata*, *Parthenium hysterophorus*, *Ageratum conyzoides,* and *Ageratum houstonianum* (Table 4.1).

Table 4.1. List of dominant native (20) and invasive (6) plant species included in the reference plant list. Reference plant list used in the preference ranking and pile sort activities with community members. Species chosen for this list were identified within the riverine forests along the Rapti River of Western Chitwan Valley.

Status	**Scientific name**	**Nepali name**	**English common name**	**Growth form**
Dominant invasive	*Ageratum conyzoides*	Seto gandhe	Goatweed	Herbaceous
	Ageratum houstonianum	Nilo gandhe	Bluemink	Herbaceous
	Chromolaena odorata	Banmara	Siam weed	Shrub
	Lantana camara	Kande Banmara	Lantana	Shrub
	Mikania micrantha	Lahare banmara	Mile-a-minute weed	Vine
	Parthenium hysterophorus	Gajar jhar	Santa Maria feverfew	Herbaceous
Dominant native	*Acacia catechu*	Khayer / Khair	Cutch tree	Tree
	Bombax ceiba	Simal	Silk-cotton tree	Tree
	Clerodendrum infortunatum	Bhanti	Hill glory bower	Shrub
	Colebrookea oppositifolia	Dhursilo	Squirrel tail	Shrub
	Cynodon dactylon	Dubo	Bermuda grass	Grass
	Dalbergia sissoo	Sisau	Indian rosewood	Tree
	Desmodium triflorum	Chariamiliki mausi	Tick clover	Herbaceous
	Dicranopteris linearis	Unyu	False staghorn fern	Fern
	Dryopteris cochleata	Niguro / Neuro	Wood fern	Fern
	Imperata cylindrica	Siru	Cogon grass	Grass
	Leersia hexandra	Karauti jhar	Cut grass	Grass
	Litsea monopetala	Kutmiro	Litsea	Tree
	Piper longum	Pipla	Long pepper	Vine
	Pogostemon benghalensis	Rudilo	NA	Herbaceous
	Rungia pectinata	Khursani jhar	Pepper grass	Herbaceous
	Saccharum spontaneum	Kans	Wild sugar cane	Grass
	Shorea robusta	Sal	Sal tree	Tree
	Trewia nudiflora	Bhellar	Rhino apple	Tree
	Urtica dioica	Sisnu	Stinging nettle	Shrub
	Ziziphus nummularia	Bayar	Lote bush	Shrub

Ethnobotanical interviews. In order to identify survey respondents who possess a strong connection to plant resources and have plant knowledge, we recruited respondents using a chain-referral method (snowball sampling) (H. R. Bernard, 2011; R. H. Bernard & Bernard, 2012). All respondents lived within walking distance (less than 20 minutes) of a CF along the Rapti River and their households were generally located in the following three rural municipalities of Chitwan district that border the Rapti River: Jagatpur, Meghauli, and Sukranagar (Ministry of Federal Affairs, Nepal; prior to their formal dissolution in 2017, these municipalities were referred to as Village Development Committees).

We conducted in-depth ethnobotanical interviews with 30 individuals using ecological and ethnographic techniques including quantitative exercises such as free listing, pile sorting and preference ranking (Bernard, 2011). We chose three overlapping techniques, a process called triangulation, to increase the reliability of generated themes and minimize inefficiency in data collection (Jonsen & Jehn, 2009). We verified themes generated through these quantitative exercises by conducting semi-structured interviews. Further, we conducted a pairwise comparison of common ecological problems (hereafter referred to as hazards) to determine how people rank or perceive the risk of invasive plants relative to other natural and anthropogenic perturbances.

We recorded all the interviews with permission from the respondents. After each interview, all respondents were offered chocolate and a small gift (less than $1 USD) as a token of appreciation for their time. The IRB determined that the protocol is considered exempt pursuant to Federal Regulations 45CFR46(2) tests, surveys, interviews, or observation (Study #00006022).

Respondent selection. We conducted ethnobotanical interviews with 30 individuals, 15 men and 15 women, at two different times: a primary interview and follow-up, which allowed us to generate informed, semi-structured interview questions regarding plant invasion and CF management as well as to identify species cited within individual free lists. The first interviews took place in January 2018 and follow-up interviews in April 2018. The primary and follow-up interviews were conducted with the same respondents and ranged from 45 to 150 minutes, with a 97% response rate on the follow-up interview. All respondents performed the same survey exercises and received the same structured interview questions; only impromptu, semi-structured follow-up interview questions may have differed among respondents.

We categorized respondents based on gender and ethnic or migrant group, including indigenous and internal migratory persons (people who are of a non-indigenous ethnic group who moved to the Chitwan Valley from other regions, excluding the Terai lowlands, of Nepal). We recruited 10 individuals, equally split by gender, from each ethnic/migrant group for a total of 30 respondents. The categories are based on generalizations of ethnic identity:

1) Indigenous: Individuals from ethnic castes indigenous to the Terai (ethnic identity: Tharu, Kumal, Darai, and Bote)
2) First wave migrants: Individuals who migrated to the Terai between 1950 and 1975 from other regions of Nepal (ethnic identity: Bhramin, Chhetri, Gurung, Tamang, Newar, and others)

3) Second wave migrants: Individuals who migrated to the Terai after 1975 or were born from internal migrant parents after 1975 (after the construction of the main highway) (ethnic identity: Bhramin, Chhetri, Gurung, Tamang, Newar, and others)

Respondents belonged to only one of the ethnic/migrant groups above and collected forest resources or entered the forest at least one day each month. All respondents self-identified as plant collectors, traditional healers, or plant cultivators (i.e. subsistence or agricultural farmers, herbalists, or gardeners). Of the respondents, women went to the forest on average 58 days per year more than men. Most respondents were non-literate and had no formal schooling or less than three years of secondary schooling. Respondents could list more than one occupation, but most selected ‘Farmer’ as their dominant occupation and source of income (Table 4.2). Respondents who selected day-laborer were Dalit (referring to low-caste in the Hindu caste system) or ethnically indigenous, perhaps because these groups are least likely to own property to farm (Guinée, 2014). Respondent ages ranged from 26 to 78, however, it should be noted that most women respondents did not know their true age and had to approximate based on the year they were married or had children. In the demographic data, we report 31 respondents, because one respondent could not complete the pile-sort portion of the interview, so only demographic data were collected. We interviewed a new respondent, but this individual could not complete the follow-up interview.

Table 4.2. Demographic information about respondents (n = 31). One respondent could not complete the interview though their demographic data are reported here. Respondents were asked to report their occupation (dominant source of income) and were allowed to state more than one source.

			Age	**Days entered the forest**	**---------------------Education-------------------**				**---Occupations (could state more than one)---**				
Gender	**Ethnic group**	**Number of respondents**	**Mean ± SD**	**Mean ± SD**	**No school**	**Some secondary**	**Any high school**	**High school certificate**	**Farmer**	**Fisher**	**Day laborer**	**Small business owner**	**Traditional healer**
Women	Overall	16	43.9 ±12.2	200.3 ± 126.3	6	9	1	0	15	0	2	1	0
	Indigenous	6	44.8 ±10.7	222.0 ± 160.1	4	2	0	0	5	0	2	0	0
	First wave migrant	5	53.2 ±10.4	127.2 ± 76.6	2	3	0	0	5	0	0	0	0
	Second wave migrant	5	33.6 ±7.9	247.2 ± 108.5	0	4	1	0	5	0	0	1	0
Men	Overall	15	54.1 ±14.6	154.9 ± 135.0	4	5	3	3	11	1	1	2	2
	Indigenous	5	56.8 ±10.7	76.8 ± 80.8	2	1	0	2	3	1	1	2	1
	First wave migrant	5	67.0 ±9.9	191.0 ± 142.8	2	2	0	1	4	0	0	0	1
	Second wave migrant	5	38.4 ±3.4	196.8 ± 159.3	0	2	3	0	4	0	0	0	0

Free listing – what plants are important to people's lives and livelihoods? Free listing is an elicitation technique used in cultural domain exploration and analysis. This survey technique is common in ethnobotanical studies of medicinal plants, and its use is well-established in the field (Malan & Neuba, 2011). Each respondent was asked to free list, in 10 minutes, all the plant species they considered valuable to their lives or livelihoods. After the free list, we asked respondents to identify whether the plant could be found in the forest, village, or national park. For example, many respondents cited Ocimum sanctum as important (Nepali name: Tulsi; common name: holy basil), which is a plant commonly cultivated in people's gardens or near their homes (used for religious/spiritual purposes in Nepal) but rarely found in the forest. As our intention was to gain a better understanding of non-cultivated plants, we then excluded all non-forest plants to reduce people's free list to a 'forest plant free list.' This list of 'forest plants' was defined by the respondents and not by the researchers.

From the results of the free list exercise, we calculated the number of times the species is listed (frequency) and the order in which the species is listed (rank), because individuals tend to recall the most culturally salient species first (Sutrop, 2001). Further, all respondents were asked to describe the species listed in terms of the plant's potential utility (how it is used or consumed), medicinal value, season of growth and collection (if collected), morphology, other identifying names, and where the plant grows or can be collected (forest, village, and/or national park). We determined the most cited plant species (frequency) and their relative position on the list (mean order).

Pile sorting – how do people categorize plants (native or invasive)? Pile sorts are another form of cultural domain analysis from cultural anthropology that is used to investigate knowledge about specific domains by eliciting similarity judgements ; in this case, of plant species categories (Wilson & Dufour, 2006). For example, people may categorize plants based on their aesthetic characteristics, spiritual value, utility, nativity, or morphological structure depending on their experience, worldviews, life-world (new ways of learning), or sense of community (Miller, 2016; Singh, 2008; Sykes, 2009). Using the 26 plant placards of the reference plant list (dominant invasive and native plant species from the riverine forests; Table 4.1), we asked each respondent to create any number of mutually exclusive groups (referred to as piles) for each plant. We did not provide instructions for what the piles should be (non-directed pile sort); we only asked that they be able to name each grouping after they completed their piles. After naming each pile, the respondents were asked to again sort the piles into any additional mutually exclusive groups, resulting in no more than 25 individual piles (at least one plant must be placed in a group). After each sorting event, the respondents were asked to give a new name or phrase to the pile to distinguish its characteristics. We used the pile names and plant species in each pile to determine how individuals categorize plant species. Few people (six respondents) created additional piles after the initial sort, and if they did create additional piles, they only created one more. We simplified our analysis by restricting the data to only the first set of piles created by each respondent.

Pile names vary among respondents but could have the same general theme, so we coded each pile rationale to determine the main theme of the pile name and calculated the percent frequency of each pile name for the 26 plants and by each social group (Table 4.4). The main pile themes include: ‘Utility’ refers to whether the plant was used as firewood, fodder, thatch, medicine, food for humans or animals, other purposes, or the respondent indicated the plant had no use; ‘Physical structure’ refers to the size, height, shape, color, venation, or any physically identifiable characteristic of the plant; ‘Growth habit’ refers to the location of where or manner of how a plant grows, or the season/timing of growth; ‘Harmful’ refers to any negative aspects of the plant like being poisonous, harming other plants, contributing to forest loss, or avoiding the plant to prevent harm; ‘Unknown plant’ refers to plants that were unfamiliar to the respondent.

Preference ranking of reference plant list - Plant use and value. In ethnobotanical surveys, quantitative assessments have been employed to compare species use and importance using a preference ranking scale along with qualitative data to describe how the plant is used or how a person experiences or relates to the plant (Giday, Asfaw, & Woldu, 2009). Since invasive plants are relatively new to the plant community, there may be less known about their properties (use, habitat, and growth form) compared to native species. Often in ethnobotanical approaches, knowledge of plant use is conflated with *actual* use, but knowing how a plant may be used may differ from actually relying on or using that plant.

To explore this issue, we asked respondents to describe their knowledge of the dominant plant species (placards) and then to rank plant species in order of importance to their life and livelihoods. We then asked respondents to consider whether they use the plant personally or in their household, and we documented how or why the plant is used. We analyzed the preference rankings to determine whether social groups (men, women, indigenous, and migrant groups) consistently rank all plant dominant plant species in the same way. Using a one-way ANOVA, we assessed statistical differences to determine if different social groups (ethnicity or gender) rank native and invasive species differently. We documented plant uses for each of the 26 reference plants.

We then asked the respondents to define whether they would prefer if each plant were to increase, decrease, or remain neutral in abundance in the forests. Answers to this question could indicate any perceived problem species in the forest without directly asking which plants are considered harmful or invasive. We summed, for each of the 26 plants, the total instances where individual plant abundance was preferred to 'increase', 'decrease', or 'remain the same' and determined whether there were consistencies among plants that were framed as 'decreasers' suggesting that they are less desirable or overly abundant in this system.

Pairwise hazard ranking. In order to identify whether invasive species are perceived as a risk relative to other natural or anthropogenic problems, we administered a pairwise ranking analysis of the most commonly reported hazards (Figure 4.4). We identified this list of the six most common hazards from the 2013-2014 household survey in which respondents were asked "What do you think the biggest problems are for your community forest?" Overall, there were 37 CF problems identified that were generalized into seven common themes, however we excluded one problem related directly to CF management 'lack of restoration work/technologies' (e.g. lack of a solar power system, fence, or viewing tower). We chose to only include problems that were directly associated with environmental properties/problems. The final list of six environmental problems include: forest fire, invasive/harmful species, over-harvesting of resources (reported as a shortage or high-demand for forest products), river flooding, riverbank cutting, and wild animal attacks/conflicts. We asked respondents to participate in pairwise ranking exercises because it is a relatively easy exercise to understand and can be analyzed quantitatively to determine an overall risk index (Addis, Asfaw, & Woldu, 2013). The pairwise ranking exercise is implemented by showing each respondent two paired images (with text) of each hazard and asking them to rank which hazard was more problematic. This pairwise assessment continued until all six images were comparatively ranked (for example, if items A, B, and C are in a list, then consider the following comparisons: A vs. B; A vs. C; B vs. C).

Wild animal (attack/conflict)

Flooding

River-bank cutting

Resource Over-harvesting

Invasive species

Forest fires

Figure 4.4. Photos of six common problems (natural hazards) in community forests as reported by Western Chitwan survey respondents (from 2013-14 household survey). In this study, interview respondents ranked these photos using pairwise comparisons.

Semi-structured interview questions. We asked each respondent up to 10 semi-structured interview questions about forest management, human-wildlife conflict, acquisition of plant species knowledge, and general forest habits. Interviews were not fully translated; rather, general themes and some verbatim responses were written in Nepali and later translated to English. We also kept detailed notes about each interview and interview response in English. In the context of this paper, we use the interviews to provide supporting quotes about the perceptions of and relative sentiment towards invasive plants.

RESULTS

What plants are considered important to people's lives and livelihoods? We analyzed the free list to determine the number of plants cited as being important to an individual's life or livelihood. Overall, 30 respondents cited 1108 plants (the full plant list length for all respondents combined), of which there were 417 unique species. Some species cited were 'village plants', those that are cultivated, harvested, or purchased in the village, agricultural areas, or roadsides, but *not* found in the forest. Since this study is intended to inform forest management, we omitted village species from the free lists and calculated the average number of plant citations based on the reduced 'forest plant' free list (Table 4.3). From the 1108 plant citations, 783 citations were plants that could be found in the forest of which there were 273 unique plant species cited by respondents. That is, 273 forest plant species were identified by 30 respondents as being important to their lives and livelihoods.

Table 4.3. Free list length summaries by gender and ethnic group. List length (number of citations) represented as the mean number of plants cited ± standard deviation for each interview group (separated by ethnic identity and gender). Village and forest plants (the entire free list) can include plants that are cultivated, purchased at a market, or collected in the forest. The entire free list was filtered for 'forest plants' - the plants that could be found in the forest, according to the respondents.

		---------- Mean free list length ± SD ----------	
Ethnic group	**Gender**	**Village (farmland) and forest plants**	**Forest plants**
Indigenous	Overall	26.4 ± 10.4	20.27 ± 8.60
	Women	23.3 ± 10.9	21.50 ± 11.15
	Men	30.0 ± 9.5	18.80 ± 4.97
First wave migrant	Overall	35.6 ± 14.3	28.10 ± 15.63
	Women	35.2 ± 9.5	24.60 ± 8.96
	Men	36.0 ± 19.2	31.60 ± 20.95
Second wave migrant	Overall	46.2 ± 19.6	27.90 ± 13.59
	Women	45.0 ± 22.9	25.60 ± 17.50
	Men	47.4 ± 18.3	30.20 ± 9.81

The length of a free list indicates the total number of plants that were listed by any respondent as being important to their lives or livelihoods. We expected that because women are the dominant forest resource collectors, they may cite more plants as being important. We found that on average, migrant women cited fewer plants (mean plant list length: 24 plants) than migrant men (mean plant list length: 31 plants) (Table 4.3). But indigenous women and men had relatively similar plant list lengths, where women cited on average 21.50 forest plants and men cited 18.8. Surprisingly, across all three ethnic groups, second-wave migrants (individuals who migrated to or were born in Chitwan after the 1975) cited the highest number of plants on average (46 species) which is 15 more plant species than ethnically indigenous individuals (Table 4.3). However, when considering only forest plant citations, indigenous groups cited the least plants on average (mean 20.27 plants cited) and first wave migrants cited the most (mean

28.10 plants cited). The high amount of non-forest plants (those that are only available in the village or through commercial agriculture) referenced by second wave migrants indicates that plants from areas outside of Chitwan play a larger role in their lives and livelihoods than regionally native plants; however, this does not mean that invasive, non-native plants play a large role in their lives. Although indigenous individuals reported fewer plants in their free lists, the majority of their lists were plants that are regionally from the forest (rather than commercial agriculture or village-grown plants).

When questioned about plants that are important to their lives and livelihoods, respondents mostly cited tree species. In particular, the following tree species were cited in more than 70% of all free lists: *Bombax cieba*, *Dalbergia sissoo*, and *Shorea robusta* (Appendix J). It was not surprising to find that tree species were among the most important plants identified because they are often sources of timber, fuelwood, fodder, and food (fruits). Further, trees are also valued for spiritual purposes. For example, the *Shorea robusta* tree was often cited for the use of its leaves as a part of spiritual/religious worship (puja) (Figure 4.5).

Figure 4.5. Image of Sal leaf. A Brahmin woman holding a Sal (*Shorea robusta*) leaf formed into a plate. The image was taken on Hartalika Teej Puja, a festival for women in Nepal usually celebrated among Hindus in the month of September. Photo used with permission.

Surprisingly, some common invasive plant species were cited as being important to people's lives. 16% of the respondents cited *Ageratum conyzoides*, an invasive plant, as being a source of medicine for cuts or as a natural pesticide that could be used in agricultural fields. Other invasive plants cited include: *Mikania micrantha* (9.68 % frequency cited) used as goat fodder, *Ageratum houstonianum* (12.9 % frequency cited) used as medicine for cuts and agricultural crops, and *Chromolaena odorata* (9.68 % frequency cited) typically collected for firewood or as a material to build fences (Appendix J).

What plants are preferred? Prior to the ethnobotanical interviews, we conducted an ecological survey to determine the 26 dominant invasive and native plants within the Rapti river CFs and documented them in a reference plant list (Table 4.1). We used this reference list to determine whether dominant forest species are relied upon (collected, used, or valued in some way) or if any dominant plant species are perceived as overly abundant or an obstruction to people's livelihoods.

We asked each respondent to rank the 26 reference plant species in order of preference or importance to their lives and livelihoods. We found that on average, trees were the lowest ranked plants (indicating that they are the *most* preferred species). Surprisingly, the dominant tree species (*Shorea robusta*, *Dalbergia sissoo*, and *Bombax cieba*) from the ecological survey (Table 4.1) were also the most preferred (lowest ranked species) by all social groups (Appendix K). When considering different genders, almost all women cited *Shorea robusta* as the most important species (ranked in the first position) from the dominant reference plant list (Figure 4.6).

When considering different ethnic groups, respondents all generally ranked native and invasive plants in the same way (no significant differences between ranks of individual species) (Appendix K). However, one invasive plant species, *Ageratum houstonianum* was ranked as relatively preferable for indigenous ethnicities compared to migrant groups (Figure 4.7). Indigenous respondents often cited the medicinal properties of *Ageratum* as being a main reason for its more preferable ranking. On average, invasive plants were the least preferred species by all groups (Appendix K). Overall, most invasive plants were given a ranking no higher than 12/26 by most respondents.

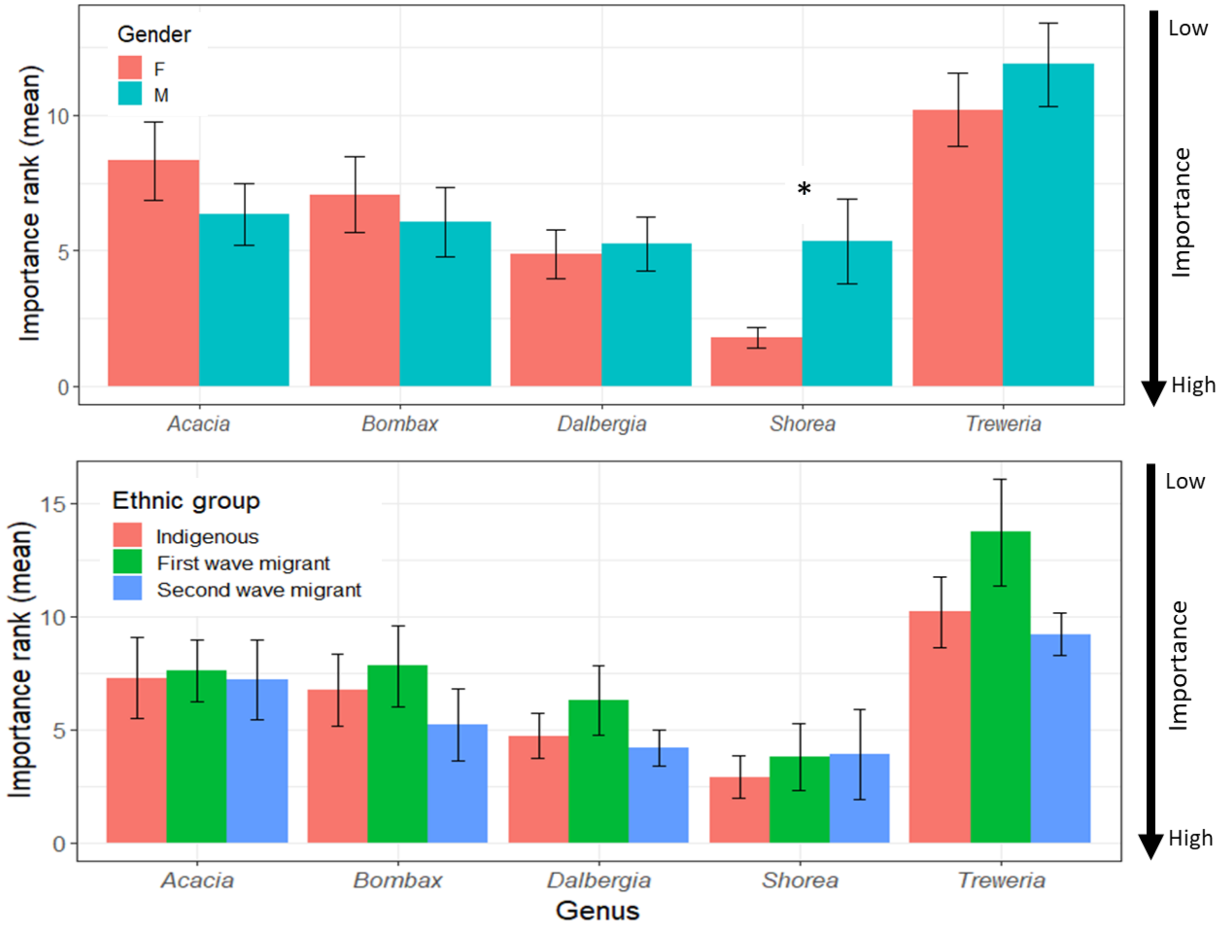

Figure 4.6. Dominant tree species in community forests (of 26 plants on reference list) that are ranked as important for respondents' life and livelihoods. A rank of 1 (lower values) signifies that the plant is the most important and a rank of 26 represents the least important. Ranks averaged within genders (men and women; top graph) and ethnic groups (indigenous, first wave migrant, second wave migrant; bottom graph). Error bars are standard deviations. Asterisk indicates significant difference at p=0.05 level.

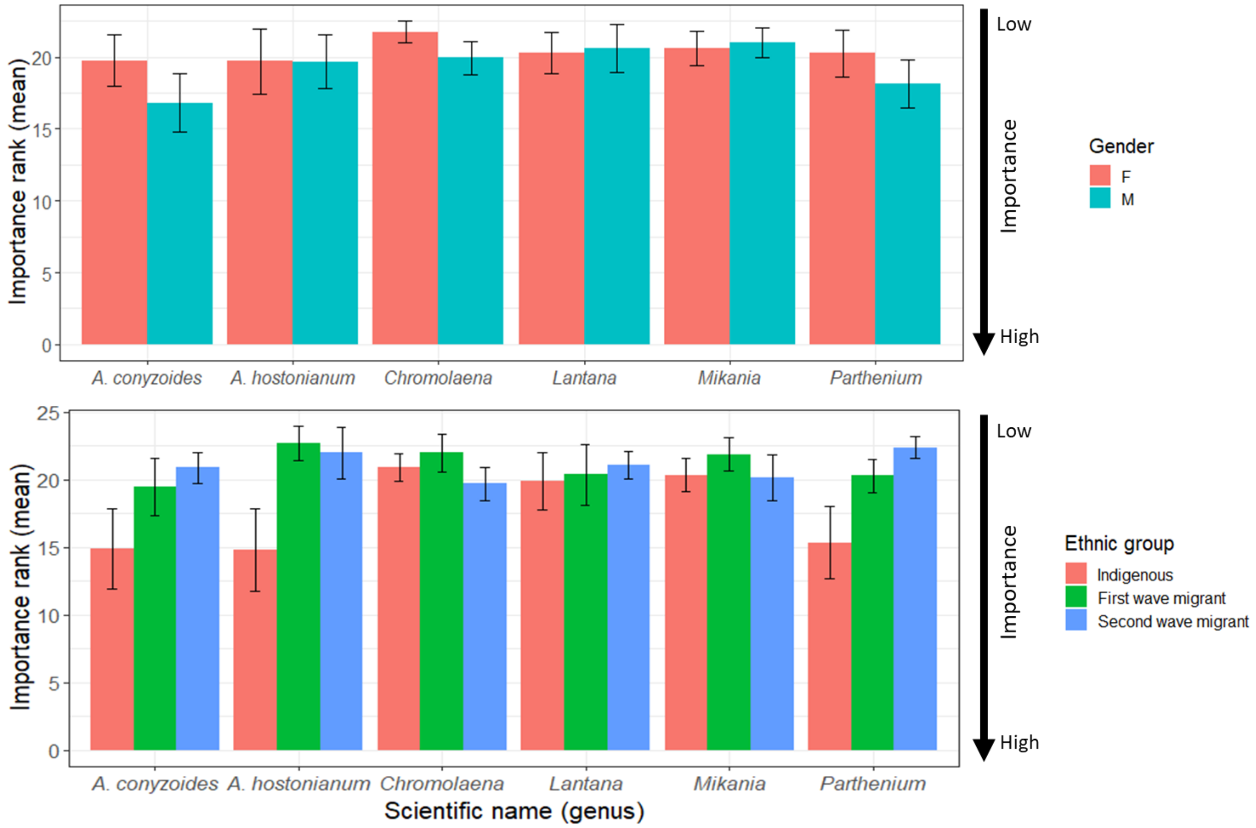

Figure 4.7. Dominant invasive species (of 26 plants on reference list) that are ranked as important for respondents' life and livelihoods. A rank of 1 (lower values) signifies that the plant is the most important and a rank of 26 represents the least important. Ranks averaged within genders (men and women; top graph) and ethnic groups (indigenous, first wave migrant, second wave migrant; bottom graph). *A. conyzoides* and *A. houstonianum* are the congeneric species from the genus *Ageratum*. Error bars are standard deviations.

Though not ranked significant differently among social groups, *Parthenium* was ranked surprisingly low (indicating that this is a more preferred invasive plant) by indigenous groups than other ethnic groups (mean rank of 16 out of 26). When asked why *Parthenium* was in a lower rank position (indicating more preferable), respondents stated that it could be used for worship (puja). Though the interviewers clarified that the plant was referred to as *Parthenium* (Nepali name: Gajar pate jhar), it is morphologically very similar to *Artemisia indica* (Nepali name: Titepati) a plant commonly used to make incense or for religious worship in Nepal. Despite this clarification, respondents from indigenous groups still ranked *Parthenium* as being a slightly more preferred species than other social groups citing that the flowers can be used as offerings in worship.

How do people categorize and conceptualize plants (native or invasive)? Concepts of how cultural domains, like plant species, are categorized can fundamentally differ between social groups. We asked respondents to perform a pile sorting exercise in order to determine how plants are categorized based on a person's worldview. After sorting the 26 plant placards into groups based on their similarity, respondents were asked to name each group (pile) they created. There were five main themes that emerged from the pile names: Utility, Physical structure (growth form), Growth habit (location or season of growth), Harm, and Unknown (respondent chose this category if they were unfamiliar with the plant; they were not asked to make this pile). Surprisingly, the utility (or lack of use) of a plant species was the most commonly created pile that respondents formed. This indicates that plants are commonly perceived based on the function that they provide, rather than their morphological features (Appendix L). The importance of utility was further reinforced by the presence of the pile "Unknown plant" which suggests that respondents did not feel comfortable categorizing a plant if they were not familiar with its use. For example, a forest user would categorize a plant as ‘unknown’ before categorizing the plant based on a physical feature. Species were never categorized based on their nativity (region they are from), indicating that forest users may not consider invasiveness or nativeness in the cultural domain – plants.

When considering different social groups, indigenous women cited 93% of the 26 dominant plant species based on their utility, whereas men cited 77% of plants in this category (Table 4.4). On the other hand, migrant ethnic groups had relatively similar citations of utility even between genders. For example, both men and women from first wave and second wave migrant groups cited utility as a characteristic of 93% of plants. The second most commonly cited characteristic was the physical structure or growth form of the plants. However, this category was predominantly created by men respondents. For example, first wave and second wave migrant men cited the physical structure of the plant up to 10 times more often than women in the same ethnic groups (Table 4.4). Men from second wave migrant ethnicities also cited a plant’s ‘growth habit’ (season, location, or habit of plant growth) more than any other group (17% of plants were cited based on this characteristic).

Table 4.4 Percentage of dominant forest plants (26 species) categorized by respondents (by social group) across five pile themes.

Ethnic identity	Gender	Number of respondents	Mean ± SD amount of piles	Percentage of plants categorized as each pile theme				
				Utility	Physical structure (growth form)	Growth habit (seasonality or location)	Harmful	Unknown plant
Indigenous	Overall	10	9.5 ± 4.97	85.77	18.46	3.85	4.62	3.85
	Women	5	9.0 ± 2.74	93.85	16.92	4.62	4.62	0.77
	Men	5	10.0 ± 6.89	77.69	20.00	3.08	4.62	6.92
First wave migrant	Overall	10	8.6 ± 2.32	93.85	9.23	3.46	3.85	0.38
	Women	5	8.4 ± 2.41	94.62	2.31	0.00	3.85	0.00
	Men	5	8.8 ± 2.49	93.08	16.15	6.92	3.85	0.77
Second wave migrant	Overall	10	6.9 ± 2.60	93.08	11.15	9.62	4.62	1.92
	Women	5	7.8 ± 2.77	96.92	2.31	1.54	6.92	1.54
	Men	5	6.0 ± 2.35	89.23	20.00	17.69	2.31	2.31

Plant use and value – are invasive plants used? Knowledge about how plants are used or could be used does not capture whether a plant is utilized by the respondent. For example, though respondents might conceptualize plants based on their utility (or lack of utility), they may not be using those species to support their lives and livelihoods. When unprompted, respondents cited that some invasive plants were important to their lives and livelihoods. However, when prompted with plant placards (visual cards) of the dominant 26 plant species, up to 47% of respondents reported personally (themselves) using at least one invasive plant (Appendix M). Notably, the most prolific invasive plant in the forest, *Mikania micrantha,* was one of the most commonly used invasive plants (47% of respondents use this plant). However, we know from the free list and preference ranking, that *Mikania* is not a preferred plant. Further, 73% of respondents said they would want *Mikania* to decrease in abundance in the forest. In addition, *Ageratum houstonianum* is a slightly more preferable plant (lower ranking than *Mikania*) and has some cultural relevance (mentioned in free lists), but 80% of respondents still reported that they would want this plant to decrease because it was overly abundant. The most commonly cited uses of *Mikania* and other invasive plants were as: goat fodder, medicinal/healing properties, animal fodder, fencing materials, and flowers used for worship.

Risk perceptions of environmental hazards. Risk perception of environmental hazards has reportedly been documented as having gendered differences, where women are more likely to perceive risks than men (Bord & O’Connor, 1997; Elias et al., 2017). For this reason, we calculated the average perceived rank of six different environmental hazards for both women and men, separately. We found that women ranked invasive species as fifth out of six environmental hazards, while men ranked them as the fourth most important environmental hazard (Table 4.5).

Women ranked invasive plants slightly higher than wildfires in terms of how critical it would be for them to manage or respond to these issues. Men cited riverbank cutting as the most important environmental hazard, often stating that cutting meant losing community-forest land area to the river. Overall, most women cited conflict with wild animals as their main environmental concern (Table 4.5).

Table 4.5. Six common problems in community forests ranked by importance by respondents, split by gender and ethnicity/migrant status. A rank of 1 (lower values) signifies that the hazard was considered to be most problematic and a rank of 6 represents that it was considered to be the least problematic. The sum total of all pairwise scores given within that category (ethnic group or gender) we ordered based on rank (1 to 6).

		Total pairwise rank score					
Group	**Category**	**Wild animal attacks**	**Riverbank cutting**	**Flooding**	**Over-harvesting resources**	**Invasive plants**	**Wildfires**
Ethnic group	Indigenous	2	1	3	5	4	6
	First wave migrant	2	1	3	5	6	4
	Second wave migrant	1	2	3	5	4	6
Gender	Women	1	2	3	4	5	6
	Men	2	1	3	6	4	5

DISCUSSION

The diversity of human perspectives in social-ecological systems could influence forest management acceptability and practice. However, relatively few studies have explored the complexities of belief systems as they apply to environmental challenges, like invasive plants and their management. Restoration ecologists and land managers can take an adaptive-management approach that incorporates TEK and traditional practices into the development and implementation of ethnoecological restoration plans to identify and account for potential social barriers to management implementation.

Often, land managers and scientist develop educational and outreach programs to demonstrate the importance of invasive species management to community members (Callaham et al., 2006; Larson et al., 2011). However, in this study context, local people were well-aware of the negative consequences of some plant species. Respondents noted that invasive plants should decrease, that they are harmful or have little use value, and in many instances, they were described based on their negative impact on the forest or toxicity to animals. Despite understanding the consequence of invasion, almost 50% of respondents reported using invasive plants. Thus, an educational program about the ecological or social consequences of invasion is unlikely to sufficiently address the issue of invasive plant management, as community members already recognize the trade-off of using invasive plants.

Ethnicity and migration experience may influence an individual's perceptions of invasive species and their management. We would expect that because migrants are relatively new to the area, they would have different or less local ecological knowledge related to their new region (Nyhus, Sumianto, & Tilson, 2003), but our study found that the opposite was true. On average, internal second-wave migrants cited more plants and described more plant uses than any other group. This finding could be because migrants recall both plant species from their native region of Nepal and their newly established region. For example, migrants were likely already farmers prior to migrating, and thus had detailed knowledge of plant species before arriving in Chitwan. After migrating to Chitwan with the intention of acquiring farmland, migrants collected more botanical knowledge in their new location. In other studies, migrants have been shown to possess a knowledge that is related more temporally (when species arrived, or environmental changes occurred) rather than a spatial knowledge of place (Pierotti & Wildcat, 2000). Thus, the ecological knowledge of plant species might be more limited to identifying plant species rather than defining their utility or value. Similarly, we found that second wave migrants, particularly men, were more likely to conceptualize plants based on their growth habit (creeping, erect, etc.) and seasonality (timing of growth). Further, it should be noted that second wave migrants received the most formal education than any other social group (Table 4.2). More formal education has been linked with greater familiarity with and preference for different plants, especially among women (Hami & Tarashkar, 2018).

In general, men visit the CFs less often than women because cultural norms encourage women to be the resource collectors for their household (Lawoti & Guneratne, 2010). Yet, men were more likely to cite longer lists of plants that were important to their lives and livelihoods than women. However, when accounting for non-village plants and including only forest plants, men's free list length did not differ from the average woman's list length. Thus, while men may express more plants as important to their lives, those plants are generally not collected in the forest. Further, in Western Chitwan Valley, 97% of households that rely on forest resources say that at least one woman collects resources for their household (Chapter 1). This relationship between women and forest resources places women at the forefront of conservation, by making them responsible for sustainable forest-management and harvesting practices (Agarwal, 2010). At the same time, women are under-represented in decision-making groups (Agarwal, 2001), and thus have little opportunity to contribute their perspectives about plants and resource management.

Women and men tend to conceptualize plants based on their use or value. For example, greater than 85% of all respondents referred to plant use in all of the categorizations of plants. However, men also considered plant morphology and physical structure as a main part of categorizing plants. In contrast to most definitions of invasive species, as they would be conceptualized in scientific disciplines, respondents did not mention plant nativeness as a part of their categorizations. Surprisingly, only a maximum of 6% of plants were cited as being harmful (plants were never cited as being good, but some were cited as being 'bad,' 'not liked,' or 'causing harm'). Thus, how forest users conceptualize plants can be based on virtue-laden sentiments, like their negative effects (i.e. being bad).

Perceptions of invasive species are varied and depend on individual values and perception of risk (Estévez et al., 2015). Our study found that almost half of the respondents used invasive plant species in some way. Respondents who cited invasive plant species tended to be women or men from lower castes, groups that have been historically disenfranchised and are less likely to own land. Respondents from these more vulnerable populations cited invasive species as an alternative fuel or fodder source, perhaps because these plants are abundant and easy to collect in the forest and common land areas (Rai & Scarborough, 2015; Rai et al., 2012).

Some invasive plants are important to local lives and livelihoods. However, most invasive plants are only collected out of necessity or because they are abundant and often easier to access. Though the majority of invasive plants were used by at least 10% of respondents, they were rarely preferred species and were often considered overly plentiful or harmful species. Thus, while respondents may use invasive plants, they are not considered to fill a critical function in everyday life.

Though invasive plants are considered an environmental problem, they are ranked as relatively low risk compared to other natural hazards. Notably, women are particularly more concerned about wild animal attacks and wildlife/human conflict than any other environmental hazards. Further, men consider wild animal conflicts and riverbank cutting as the dominant hazards. Other studies have shown that the lay public are more likely to rank unlikely (rare), but high-consequence environmental problems as posing greater risk

(Slimak & Dietz, 2006). Invasive plants, though they are of less concern than other challenges, are also the most feasible issue for forest users and mangers to control at the local level. For example, forest users can change their resource harvesting habits, actively clean or remove invasive plants, or find other management solutions. However, risks like wildlife conflict, flooding, and other natural disasters may seem out of the forest user's ability to control. Thus, further studies should be explored to determine whether invasive plants, though considered relatively low risk phenomena, are more likely to be prioritized in management.

In social-ecological systems, ethnic diversity, familiarity with natural-resource collection, and social status may alter individual perspectives on invasive species and forest management. But the imbalance between decision makers (CF managers) and forest users has not been accounted for in forest management decisions and can lead to conflicts. For example, because some invasive plants are considered useful even if they are not preferred, management plans that aim to eradicate invasive plants could eventually contribute to a resource void if they are not re-planting with other desirable or beneficial species. Given that forest users are most concerned with plant use rather than the environmental function or physical characteristics of the plant, potential restoration programs should consider re-vegetating with desirable species to promote livelihood resource sustainability. By using ethnoecological approaches, like free listing elicitation and pile sorting, restoration ecologists can identify ecologically and culturally salient species to be used in re-vegetation. Further, by soliciting stakeholder perceptions and integrating local ecological knowledge or TEK, adaptive management plans that are community-led and locally generated are more likely to have forest user engagement.

Invasive species can have inherent value and cultural value, and there may be moral/ethical limitations to mitigating their impacts that can disrupt current invasive-species management approaches and policies (Crowley et al., 2017a). Perspectives on invasive species may influence the ways we manage those species. If these multiple viewpoints are not acknowledged, we run the risk of creating conflicts between managers and stakeholders, or under-representing marginalized groups in management decisions (Shackleton et al., 2007; Shackleton, Shackleton, & Kull, 2019).

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APPENDIX A

DESCRIPTIVE STATISTICS FOR THE SOCIAL AND ECOLOGICAL PREDICTOR VARIABLES USED IN REGRESSION MODELS.

Descriptive statistics for the social and ecological predictor variables used in regression models. Percent of plots indicates the fraction of all plots (x100) within an ecosystem type (n varies by ecosystem) where that activity or species occurred. Percent of plots where a variable is present is not calculated if the variable could not be represented as present/absent (i.e. richness and canopy cover), was reported as an index (EVI), or has units other than counts (elevation, slope, and distance). In plots where a minimum of one activity (individual or collective) occurred, the mean, median frequency of occurrence, and range of each activity was calculated. In ecosystems where an activity occurred but was only reported once per plot (no overlap), then the mean, median, and range of that activity are equal to 1.

Activity Type	**Predictor variables**	**Statistic**	***Bombax* mixed forest** **n = 620**	***Dalbergia* mixed forest** **n = 517**	***Shorea robusta* forest** **n = 828**	**Grassland** **n = 254**	**All ecosystem types** **n = 2219**
Individual activities	Firewood collection (count)	% of plots	44	32	46	21	39
		Mean (SD)	1.96 (1.00)	2.12 (1.36)	2.75 (1.79)	1.70 (1.08)	2.32 (1.51)
		Median	2.00	2.00	1.00	2.00	2.00
		Range (Min-Max)	1-7	1-8	1-8	1-5	1-8
	Thatch collection (count)	% of plots	20	7	1	15	9
		Mean (SD)	1.84 (1.20)	1.58 (0.81)	1.00 (0.00)	1.65 (1.18)	1.72 (1.12)
		Median	1.00	1.00	1.00	1.00	1.00
		Range (Min-Max)	1-7	1-4	1-1	1-6	1-7
	Fodder collection (count)	% of plots	40	20	27	11	27
		Mean (SD)	2.38 (1.74)	1.74 (1.23)	1.77 (1.22)	2.15 (1.29)	2.03 (1.49)
		Median	2.00	1.00	2.00	1.00	1.00
		Range (Min-Max)	1-10	1-7	1-6	1-5	1-10
	Medicinal plant collection (count)	% of plots	1	3	2	1	2
		Mean (SD)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
		Median	1.00	1.00	1.00	1.00	1.00
		Range (Min-Max)	1-1	1-1	1-1	1-1	1-1

Activity Type	Predictor variables	Statistic	*Bombax* mixed forest	*Dalbergia* mixed forest	*Shorea robusta* forest	Grassland	All ecosystem types
			n = 620	**n = 517**	**n = 828**	**n = 254**	**n = 2219**
	Grazing (count)	% of plots	1	0	0	0	0
		Mean (SD)	2.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	2.00 (0.00)
		Median	2.00	0.00	0.00	0.00	2.00
		Range (Min-Max)	1-2	0-0	0-0	0-0	1-2
	Picnic/leisure (count)	% of plots	28	11	19	3	18
		Mean (SD)	1.32 (0.72)	1.16 (0.42)	1.30 (0.51)	1.00 (0.00)	1.28 (0.60)
		Median	1.00	1.00	1.00	1.00	1.00
		Range (Min-Max)	1-4	1-3	1-3	1-1	1-4
	Evidence of recent fires (count)	% of plots	3	4	39	7	17
		Mean (SD)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
		Median	1.00	1.00	1.00	1.00	1.00
		Range (Min-Max)	1-1	1-1	1-1	1-1	1-1
	Evidence of plant cutting (count)	% of plots	7	14	11	2	10
		Mean (SD)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
		Median	1.00	1.00	1.00	1.00	1.00
		Range (Min-Max)	1-1	1-1	1-1	1-1	1-1
Collective activities	Jungle cleaning (count)	% of plots	19	13	43	5	25
		Mean (SD)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
		Median	1.00	1.00	1.00	1.00	1.00
		Range (Min-Max)	1-1	1-1	1-1	1-1	1-1
	Grass plantations (count)	% of plots	0	2	2	0	1
		Mean (SD)	0.00 (0.00)	1.00 (0.00)	1.00 (0.00)	0.00 (0.00)	1.00 (0.00)
		Median	0.00	1.00	1.00	0.00	1.00

Activity Type	**Predictor variables**		**Statistic**	***Bombax* mixed forest**	***Dalbergia* mixed forest**	***Shorea robusta* forest**	**Grassland**	**All ecosystem types**
				n = 620	**n = 517**	**n = 828**	**n = 254**	**n = 2219**
			Range (Min-Max)	0	1-1	1-1	0	1-1
	Tree plantations (count)		% of plots	3	3	2	4	3
			Mean (SD)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
			Median	1.00	1.00	1.00	1.00	1.00
			Range (Min-Max)	1-1	1-1	1-1	1-1	1-1
	Reported former fires (count)		% of plots	6	0	39	3	16
			Mean (SD)	1.00 (0.00)	0.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
			Median	1.00	0.00	1.00	1.00	1.00
			Range (Min-Max)	1-1	0	1-1	1-1	1-1
	Wetlands (count)		% of plots	2	3	3	2	3
			Mean (SD)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
			Median	1.00	1.00	1.00	1.00	1.00
			Range (Min-Max)	1-1	1-1	1-1	1-1	1-1
Governmental/ historic activities	EVI by year (range -1 to 1)	**1988**	% of plots	NA	NA	NA	NA	NA
			Mean (SD)	0.24 (0.15)	0.30 (0.19)	0.39 (0.07)	0.18 (0.16)	0.31 (0.16)
			Median	0.23	0.40	0.19	0.39	0.34
			Range (Min-Max)	0-1	0-1	0-1	0-1	0-1
	EVI by year (range -1 to 1)	**2000**	% of plots	NA	NA	NA	NA	NA
			Mean (SD)	0.37 (0.15)	0.37 (0.20)	0.45 (0.08)	0.21 (0.20)	0.38 (0.17)
			Median	0.42	0.48	0.15	0.46	0.45
			Range (Min-Max)	0-1	0-1	0-1	0-1	0-1
	EVI by year (range -1 to 1)	**2006**	% of plots	NA	NA	NA	NA	NA
			Mean (SD)	0.42 (0.13)	0.41 (0.13)	0.42 (0.05)	0.15 (0.10)	0.39 (0.13)

Activity Type	**Predictor variables**	**Statistic**	***Bombax* mixed forest**	***Dalbergia* mixed forest**	***Shorea robusta* forest**	**Grassland**	**All ecosystem types**
			n = 620	**n = 517**	**n = 828**	**n = 254**	**n = 2219**
		Median	0.46	0.47	0.17	0.43	0.43
		Range (Min-Max)	0-1	0-1	0-1	0-1	0-1
Environment factors	Understory plant richness (count)	% of plots	NA	NA	NA	NA	NA
		Mean (SD)	3.87 (0.76)	3.67 (0.96)	3.90 (0.72)	3.27 (0.92)	3.77 (0.84)
		Median	4.00	4.00	3.00	4.00	4.00
		Range (Min-Max)	1-6	1-6	3-6	0-5	1-6
	Overstory plant richness (count)	% of plots	NA	NA	NA	NA	NA
		Mean (SD)	2.27 (0.78)	2.52 (0.90)	1.30 (0.51)	0.04 (0.19)	1.92 (0.90)
		Median	2.00	3.00	1.00	1.00	2.00
		Range (Min-Max)	0-3	1-5	1-3	0-1	1-5
	Canopy cover (%)	% of plots	NA	NA	NA	NA	NA
		Mean (SD)	51.54 (39.95)	67.40 (36.35)	64.80 (30.16)	0.41 (6.22)	70.53 (28.65)
		Median	81.12	88.92	52.78	74.88	81.12
		Range (Min-Max)	0-100	0-100	0-100	0-99	0-100
	Chromolaena cover (%)	% of plots	65	26	68	15	51
		Mean (SD)	9.85 (10.86)	3.29 (6.88)	13.92 (19.11)	1.63 (4.07)	17.25 (15.92)
		Median	13.00	13.00	13.00	13.00	13.00
		Range (Min-Max)	0-75	0-50	0-88	0-13	7-88
	Lantana cover (%)	% of plots	10	22	4	0	9
		Mean (SD)	0.99 (3.56)	3.58 (10.03)	0.48 (2.67)	0.05 (0.81)	13.16(12.78)
		Median	6.50	13.00	13.00	6.50	6.50
		Range (Min-Max)	0-38	0-88	0-38	0-13	7-88
		% of plots	62	33	1	29	29

Activity Type	Predictor variables	Statistic	*Bombax* mixed forest	*Dalbergia* mixed forest	*Shorea robusta* forest	Grassland	All ecosystem types
			n = 620	**n = 517**	**n = 828**	**n = 254**	**n = 2219**
	Presence of nuisance species (count)	Mean (SD)	0.74 (0.66)	0.34 (0.50)	0.22 (0.43)	0.30 (0.49)	1.11 (0.31)
		Median	1.00	1.00	1.00	1.00	1.00
		Range (Min-Max)	0-3	0-2	0-2	0-2	1-3
	Presence of desirable species (count)	% of plots	55	32	88	97	67
		Mean (SD)	0.76 (0.78)	0.45 (0.71)	0.90 (0.36)	1.56 (0.57)	1.24 (0.44)
		Median	1.00	1.00	2.00	1.00	1.00
		Range (Min-Max)	0-3	0-2	0-2	0-3	1-3
	Elevation (meters)	% of plots	NA	NA	NA	NA	NA
		Mean (SD)	143.96 (11.13)	161.73 (11.24)	182.93 (13.26)	141.80 (11.10)	162.39 (21.09)
		Median	142.00	163.00	140.00	182.00	163.00
		Range (Min-Max)	120-181	133-183	151-222	122-181	120-222
	Slope (degrees)	% of plots	NA	NA	NA	NA	NA
		Mean (SD)	5.37 (3.24)	5.33 (3.09)	6.93 (4.11)	4.96 (3.15)	5.90 (3.63)
		Median	4.84	5.02	4.28	6.19	5.24
		Range (Min-Max)	0-19	0-16	0-26	0-19	0-26
	Tree fall (count)	% of plots	7	13	14	2	10
		Mean (SD)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
		Median	1.00	1.00	1.00	1.00	1.00
		Range (Min-Max)	1-1	1-1	1-1	1-1	1-1
	Evidence of flooding (count)	% of plots	28	39	4	96	29
		Mean (SD)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
		Median	1.00	1.00	1.00	1.00	1.00
		Range (Min-Max)	1-1	1-1	1-1	1-1	1-1

Activity Type	**Predictor variables**	**Statistic**	***Bombax* mixed forest**	***Dalbergia* mixed forest**	***Shorea robusta* forest**	**Grassland**	**All ecosystem types**
			n = 620	**n = 517**	**n = 828**	**n = 254**	**n = 2219**
	Road distance (meters)	% of plots	NA	NA	NA	NA	NA
		Mean (SD)	200.44 (154.92)	279.27 (170.07)	142.38 (120.60)	276.62 (193.36)	205.93 (162.71)
		Median	163.11	256.24	247.39	113.54	169.30
		Range (Min-Max)	0-925	0-764	0-719	3-920	0-925
	River distance in 2015 (meters)	% of plots	NA	NA	NA	NA	NA
		Mean (SD)	513.28 (373.37)	417.79 (330.11)	2684.81 (1448.23)	182.54 (149.24)	1266.02 (1436.07)
		Median	422.40	359.45	151.16	2821.09	559.13
		Range (Min-Max)	5-1737	0-1903	15-5604	0-802	1-5604

APPENDIX B

STANDARDIZED BETA COEFFICIENTS OF MODELS WITH THEIR ASSOCIATED P-VALUES FOR THE COMPREHENSIVE MODEL

Standardized beta coefficients of models with their associated p-values for the comprehensive model. The response variable is percent cover of Mikania abundance. Predictor variables are the variables that were considered to be important from the averaged subset models with delta AIC < 2. NA indicates that the variable was not included in the comprehensive model because it occurred in less than 5% of the dataset. NS indicates that the variable was not selected because it was never present in subset models with a delta AIC <2.

			Comprehensive Model			
Ecosystem type	**Model**	**Predictor variable**	**Estimate**	**SE**	**p-value**	
All ecosystem types	Individual activities	Firewood collection (count)	-0.16	0.06	<0.01	**
		Fodder collection (count)	0.13	0.06	0.05	*
		Thatch collection (count)	NS	NS	NS	
		Medicinal plant collection (count)	NA	NA	NA	
		Grazing (count)	NA	NA	NA	
		Picnic/leisure (count)	-0.10	0.05	0.03	*
		Evidence of recent fires (count)	NS	NS	NS	
		Evidence of plant cutting (count)	-0.14	0.05	<0.01	**
	Collective activities	Jungle cleaning (count)	-0.04	0.06	0.47	
		Grass plantations (count)	NA	NA	NA	
		Tree plantations (count)	NA	NA	NA	
		Reported former fires (count)	NS	NS	NS	
		Wetlands (count)	NA	NA	NA	
	Governmental/ historic activities	EVI in year 1988	-0.11	0.07	0.09	--
		EVI in year 2000	-0.18	0.07	<0.01	**
		EVI in year 2006	0.27	0.08	<0.001	***
	Environmental factors	Understory plant richness (count)	0.16	0.06	<0.01	**
		Overstory plant richness (count)	0.54	0.07	<0.001	***
		Canopy cover (%)	0.06	0.07	0.40	
		Chromolaena cover (%)	-0.02	0.06	0.72	
		Lantana cover (%)	0.15	0.05	<0.01	**

			Comprehensive Model			
Ecosystem type	**Model**	**Predictor variable**	**Estimate**	**SE**	**p-value**	
		Presence of desirable species (count)	-0.49	0.06	<0.001	***
		Presence of nuisance species (count)	0.43	0.05	<0.001	***
		Elevation (meters)	-0.49	0.08	<0.001	***
		Slope (degrees)	0.06	0.05	0.15	
		Tree fall (count)	0.06	0.05	0.27	
		Evidence of flooding (count)	0.04	0.06	0.53	
		Road distance (meters)	NS	NS	NS	
		River distance in 2015 (meters)	-0.41	0.08	<0.001	***
Bombax mixed forest	Individual activities	Firewood collection (count)	0.02	0.06	0.70	
		Fodder collection (count)	0.11	0.06	0.08	--
		Thatch collection (count)	NS	NS	NS	
		Medicinal plant collection (count)	NA	NA	NA	
		Grazing (count)	NA	NA	NA	
		Picnic/leisure (count)	-0.07	0.07	0.32	
		Evidence of recent fires (count)	NA	NA	NA	
		Evidence of plant cutting (count)	-0.04	0.06	0.51	
	Collective activities	Jungle cleaning (count)	-0.12	0.06	0.03	*
		Grass plantations (count)	NA	NA	NA	
		Tree plantations (count)	NA	NA	NA	
		Reported former fires (count)	-0.11	0.05	0.04	*
		Wetlands (count)	NA	NA	NA	
	Governmental/ historic activities	EVI in year 1988	0.03	0.07	0.71	
		EVI in year 2000	-0.18	0.08	0.02	*
		EVI in year 2006	0.55	0.09	<0.001	***
	Environmental factors	Understory plant richness (count)	0.05	0.06	0.38	
		Overstory plant richness (count)	-0.11	0.07	0.08	--
		Canopy cover (%)	0.28	0.07	<0.001	***
		Chromolaena cover (%)	0.23	0.06	<0.001	***
		Lantana cover (%)	NS	NS	NS	
		Presence of desirable species (count)	-0.19	0.07	<0.01	**
		Presence of nuisance species (count)	0.26	0.06	<0.001	***
		Elevation (meters)	-0.09	0.07	0.18	
		Slope (degrees)	-0.04	0.05	0.40	
		Tree fall (count)	0.05	0.05	0.31	

Ecosystem type	**Model**	**Predictor variable**	**Comprehensive Model**			
			Estimate	**SE**	**p-value**	
		Evidence of flooding (count)	-0.17	0.07	<0.01	**
		Road distance (meters)	0.02	0.06	0.73	
		River distance in 2015 (meters)	-0.10	0.07	0.14	
Dalbergia mixed forest	Individual activities	Firewood collection (count)	0.03	0.10	0.75	
		Fodder collection (count)	-0.07	0.09	0.49	
		Thatch collection (count)	NS	NS	NS	
		Medicinal plant collection (count)	NA	NA	NA	
		Grazing (count)	NA	NA	NA	
		Picnic/leisure (count)	0.11	0.08	0.17	
		Evidence of recent fires (count)	NA	NA	NA	
		Evidence of plant cutting (count)	-0.07	0.08	0.35	
	Collective activities	Jungle cleaning (count)	0.09	0.08	0.28	
		Grass plantations (count)	NA	NA	NA	
		Tree plantations (count)	NA	NA	NA	
		Reported former fires (count)	NA	NA	NA	
		Wetlands (count)	NA	NA	NA	
	Governmental/ historic activities	EVI in year 1988	-0.21	0.12	0.08	--
		EVI in year 2000	-0.16	0.18	0.37	
		EVI in year 2006	-0.08	0.16	0.64	
	Environmental factors	Understory plant richness (count)	0.33	0.09	<0.001	***
		Overstory plant richness (count)	-0.15	0.09	0.12	
		Canopy cover (%)	0.00	0.11	0.99	
		Chromolaena cover (%)	0.38	0.09	<0.001	***
		Lantana cover (%)	0.22	0.09	<0.01	**
		Presence of desirable species (count)	-0.93	0.14	<0.001	***
		Presence of nuisance species (count)	0.13	0.08	0.08	--
		Elevation (meters)	-0.06	0.10	0.54	
		Slope (degrees)	0.10	0.07	0.19	
		Tree fall (count)	-0.04	0.08	0.63	
		Evidence of flooding (count)	-0.22	0.09	<0.01	**
		Road distance (meters)	-0.15	0.08	0.07	--
		River distance in 2015 (meters)	NS	NS	NS	
Shorea robusta forest	Individual activities	Firewood collection (count)	0.13	0.48	0.79	
		Fodder collection (count)	0.01	0.50	0.98	
		Thatch collection (count)	NA	NA	NA	

Ecosystem type	Model	Predictor variable	Comprehensive Model			
			Estimate	SE	p-value	
		Medicinal plant collection (count)	NA	NA	NA	
		Grazing (count)	NA	NA	NA	
		Picnic/leisure (count)	0.18	0.43	0.68	
		Evidence of recent fires (count)	0.22	0.34	0.52	
		Evidence of plant cutting (count)	-0.24	0.37	0.51	
	Collective activities	Jungle cleaning (count)	0.12	0.45	0.79	
		Grass plantations (count)	NA	NA	NA	
		Tree plantations (count)	NA	NA	NA	
		Reported former fires (count)	-0.58	0.46	0.21	
		Wetlands (count)	NA	NA	NA	
	Governmental/ historic activities	EVI in year 1988	-0.70	0.45	0.12	
		EVI in year 2000	-1.37	0.51	<0.01	**
		EVI in year 2006	0.79	0.45	0.08	--
	Environmental factors	Understory plant richness (count)	0.43	0.37	0.25	
		Overstory plant richness (count)	0.28	0.34	0.42	
		Canopy cover (%)	-0.53	0.38	0.16	
		Chromolaena cover (%)	-0.89	0.55	0.11	
		Lantana cover (%)	NA	NA	NA	
		Presence of desirable species (count)	-0.66	0.34	0.05	*
		Presence of nuisance species (count)	NA	NA	NA	
		Elevation (meters)	NS	NS	NS	
		Slope (degrees)	0.07	0.35	0.83	
		Tree fall (count)	0.45	0.36	0.21	
		Evidence of flooding (count)	NA	NA	NA	
		Road distance (meters)	1.34	0.53	<0.01	**
		River distance in 2015 (meters)	0.42	0.41	0.31	
Grassland	Individual activities	Firewood collection (count)	0.52	0.43	0.23	
		Fodder collection (count)	-0.85	0.67	0.20	
		Thatch collection (count)	0.44	0.39	0.25	
		Medicinal plant collection (count)	NA	NA	NA	
		Grazing (count)	NA	NA	NA	
		Picnic/leisure (count)	NA	NA	NA	
		Evidence of recent fires (count)	0.53	0.43	0.21	
		Evidence of plant cutting (count)	NA	NA	NA	
		Jungle cleaning (count)	0.43	0.47	0.35	

			Comprehensive Model			
Ecosystem type	Model	Predictor variable	Estimate	SE	p-value	
	Collective activities	Grass plantations (count)	NA	NA	NA	
		Tree plantations (count)	NA	NA	NA	
		Reported former fires (count)	NA	NA	NA	
		Wetlands (count)	NA	NA	NA	
	Governmental/ historic activities	EVI in year 1988	0.14	0.41	0.73	
		EVI in year 2000	-0.10	0.44	0.82	
		EVI in year 2006	0.63	0.41	0.13	
	Environmental factors	Understory plant richness (count)	0.50	0.44	0.25	
		Overstory plant richness (count)	NA	NA	NA	
		Canopy cover (%)	1.81	1.60	0.26	
		Chromolaena cover (%)	NS	NS	NS	
		Lantana cover (%)	NA	NA	NA	
		Presence of desirable species (count)	-0.38	0.34	0.26	
		Presence of nuisance species (count)	0.39	0.40	0.33	
		Elevation (meters)	-1.39	0.50	<0.01	**
		Slope (degrees)	0.18	0.43	0.68	
		Tree fall (count)	NA	NA	NA	
		Evidence of flooding (count)	NS	NS	NS	
		Road distance (meters)	-0.28	0.45	0.53	
		River distance in 2015 (meters)	-0.74	0.48	0.13	

Significance codes: <0.001 '***', <0.01 '**', <0.05 '*', <0.10 '--'

SE: standard error.

APPENDIX C

INDIVIDUAL (HOUSEHOLD) ACTIVITIES QUESTIONNAIRE.

Each survey respondent was asked to indicate areas where resource collection occurred on the tablet PC map only if they reported that collection activity for their household (1094 households reported performing at least one resource collection activity).

Unit of observation:	Household member
Number of respondents:	1235
Mean number of respondents per CF:	50
Range of respondents per CF:	39 to 64
Number of responses analyzed:	1094
Total number of survey items:	388
Total number of survey items analyzed:	12
Response rate:	98.60%
Year of data collection:	2013-2014

Individual activity variables	**Survey questions**
Firewood collection	Where does your household currently go to collect firewood? Where else in last 12 months areas respondent collected firewood?
Fodder collection	Where does your household currently go to collect fodder? Where else in last 12 months areas respondent collected fodder?
Thatch collection	Where does your household currently go to collect thatch? Where else in last 12 months areas respondent collected thatch?
Medicinal plant collection	Since (month) last year, does your household collect medicinal plants? Where in last 12 months areas respondent collected medicinal plants?
Grazing	Where do you usually graze your livestock? Is it on farm land, common land, forest, community forest, national park or some other place? Where else in last 12 months areas respondent grazed animals?
Picnic/leisure	Since (month) last year, does your household go in the (community forest ___) for picnic, relax, or walk for fun? Where in last 12 months areas respondent picnicked/relaxed?

Number of household respondents from each community forest (CF) that were surveyed out of 1235 households.

CF Identifier	Number of household respondents
A	39
B	41
C	43
D	44
E	44
F	45
G	46
H	47
I	47
J	48
K	49
L	49
M	49
N	50
O	50
P	51
Q	52
R	58
S	61
T	64
U	64
Not within 5km of a CF	194

APPENDIX D

COMMUNITY FOREST MANAGEMENT (COLLECTIVE ACTIVITIES) QUESTIONNAIRE.

A member of the community forest management committee was asked to indicate on a tablet PC map where each activity occurred on a tablet PC map, only if they reported that activity for their community forest.

Unit of observation:	Community forest management committee member
Number of respondents:	21
Number of responses analyzed:	21
Total number of survey items:	802
Total number of survey items analyzed:	10
Response rate:	100.00%
Year of data collection:	2014

Collective activity variables	**Survey questions**
Jungle cleaning (count)	In the past year, where in the forest has the CF done jungle cleaning or clearing in the community forest? Please indicate the jungle cleaning areas on the map.
Grass plantations (count)	In the past year, did the CF have a grass plantation program? Please indicate the grass plantation areas on the map.
Tree plantations (count)	In the past year, did the CF have a tree plantation program? Please indicate the tree plantation areas on the map.
Former fires (count)	Fires in the community forest start for many reasons, including fires set by people, but also accidents and lighting. In the past year, about how many fires do you think happened in the community forest? Please indicate the areas of fires on the map.
Wetlands (count)	How many wetland areas has your CF ever created? Please indicate the created wetland areas on the map.

APPENDIX E

RESULTS OF MODEL SELECTION FOR ZERO-INFLATED POISSON (ZIP) AND ZERO-INFLATED NEGATIVE BINOMIAL (ZINB) REGRESSION FOR EACH ECOSYSTEM TYPE.

The response variable is percent cover of *Mikania* abundance. If the log likelihoods are significantly different, then the models suffer from over-dispersion and a ZINB model was selected.

Ecosystem type	Statistical model	Model predictor variables	df	AIC	log likelihood	p-value
All ecosystem types	ZIP	Individual activities	14	21785.43	-10878.70	**<0.001**
	ZINB	Individual activities	15	10333.44	-5151.70	
	ZIP	Collective activities	8	20751.82	-10367.90	**<0.001**
	ZINB	Collective activities	9	9931.69	-4956.80	
	ZIP	Government/ historic activities	28	18789.99	-9367.00	**<0.001**
	ZINB	Government/ historic activities	29	9092.67	-4517.30	
	ZIP	Environmental variables	50	18195.27	-9047.60	**<0.001**
	ZINB	Environmental variables	51	9016.59	-4457.30	
Bombax mixed forest	ZIP	Individual activities	14	9838.08	-4905.00	**<0.001**
	ZINB	Individual activities	15	4576.49	-2273.00	
	ZIP	Collective activities	8	9982.49	-4983.20	**<0.001**
	ZINB	Collective activities	9	4594.10	-2280.00	
	ZIP	Government/ historic activities	8	9244.07	-4614.00	**<0.001**
	ZINB	Government/ historic activities	9	4396.59	-2189.30	
	ZIP	Environmental variables	28	8716.79	-4330.40	**<0.001**
	ZINB	Environmental variables	29	4660.87	-2136.40	
Dalbergia mixed forest	ZIP	Individual activities	14	8093.43	-4032.70	**<0.001**
	ZINB	Individual activities	15	3538.70	-1754.40	
	ZIP	Collective activities	6	8366.71	-4177.40	**<0.001**
	ZINB	Collective activities	7	3556.97	-1771.50	
	ZIP	Government/ historic activities	8	8268.40	-4126.20	**<0.001**
	ZINB	Government/ historic activities	9	3507.07	-1744.50	
	ZIP	Environmental variables	26	7313.10	-3630.60	**<0.001**
	ZINB	Environmental variables	27	3382.20	-1664.10	
Shorea robusta forest	ZIP	Individual activities	14	1091.11	-531.55	**<0.001**
	ZINB	Individual activities	15	789.30	-379.65	
	ZIP	Collective activities	6	1202.71	-595.36	**<0.001**
	ZINB	Collective activities	7	787.70	-386.85	
	ZIP	Government/ historic activities	8	1264.51	-624.26	**<0.001**
	ZINB	Government/ historic activities	9	744.66	-363.33	
	ZIP	Environmental variables	28	868.21	-406.11	**<0.001**
	ZINB	Environmental variables	29	725.03	-337.52	

Ecosystem type	**Statistical model**	**Model predictor variables**	**df**	**AIC**	**log likelihood**	**p-value**
Grassland ecosystem	ZIP	Individual activities	10	513.75	-246.88	**<0.001**
	ZINB	Individual activities	11	464.51	-221.26	
	ZIP	Collective activities	NA	NA	NA	NA
	ZINB	Collective activities	NA	NA	NA	
	ZIP	Government/ historic activities	8	511.42	-247.71	**<0.001**
	ZINB	Government/ historic activities	9	464.93	-223.47	
	ZIP	Environmental variables	20	434.50	-199.25	**0.011**
	ZINB	Environmental variables	21	429.96	-195.98	

Significance codes: <0.001 '***', <0.01 '**', <0.05 '*', <0.10 '--'

SE: standard error.

APPENDIX F

LIST OF ALL VARIABLES THAT WERE SUPPORTED IN THE SUBSET MODELS WITH A DELTA AIC < 2 FOR EACH ECOSYSTEM TYPE.

Mikania abundance was the response variable in all models. Delta AIC and weights are listed for all model subsets. All selected variables were included in the comprehensive model of each ecosystem type. Bolded variables occur in all model subsets within the ecosystem type.

Ecosystem type	**Theoretical model set**	**Selected variables in model subsets**	**Delta AIC**	**Weight**
All ecosystem types	Individual activities	**Firewood** + **Fodder**	0.00	0.35
		Resource harvesting + **Firewood** + **Fodder**	0.48	0.28
		Firewood + **Fodder** + Picnic	1.17	0.20
		Firewood + **Fodder** + Picnic + Resource harvesting	1.47	0.17
	Collective activities	**Former fires + Jungle cleaning**	0.00	1.00
	Governmental/ historic activities	**EVI 1988 + EVI 2000 + EVI 2006**	0.00	1.00
	Environmental factors	**Desirable species + Distance to river + Elevation + Understory richness + Lantana cover + Nuisance species** + Slope **+ Overstory richness**	0.00	0.18
		Desirable species + Distance to river + Elevation + Understory richness + Lantana cover + Nuisance species + Overstory richness	0.06	0.17
		Desirable species + Distance to river + Fallen tree **+ Elevation + Understory richness + Lantana cover + Nuisance species** + Slope **+ Overstory richness**	1.33	0.09
		Desirable species + Distance to river + Flooding **+ Elevation + Understory richness + Lantana cover + Nuisance species** + Slope **+ Overstory richness**	1.38	0.09
		Desirable species + Distance to river + Flooding **+ Elevation + Understory richness + Lantana cover + Nuisance species + Overstory richness**	1.39	0.09
		Desirable species + Distance to river + Fallen tree **+ Elevation + Understory richness + Lantana cover + Nuisance species + Overstory richness**	1.45	0.09
		Chromolaena cover **+ Desirable species + Distance to river + Elevation + Understory richness + Lantana cover + Nuisance species + Overstory richness**	1.65	0.08

Ecosystem type	**Theoretical model set**	**Selected variables in model subsets**	**Delta AIC**	**Weight**
		Canopy cover **+ Desirable species + Distance to river + Elevation + Understory richness + Lantana cover + Nuisance species +** Slope **+ Overstory richness**	1.70	0.08
		Chromolaena cover **+ Desirable species + Distance to river + Elevation + Understory richness + Lantana cover + Nuisance species +** Slope **+ Overstory richness**	1.71	0.07
		Canopy cover **+ Desirable species + Distance to river + Elevation + Understory richness + Lantana cover + Nuisance species + Overstory richness**	1.82	0.07
Bombax mixed forest	Individual activities	Firewood	0.00	0.35
		Firewood + Fodder	0.93	0.22
		Evidence of plant cutting + Firewood	1.62	0.16
		Fodder	1.84	0.14
		Firewood + Picnic	1.91	0.14
	Collective activities	Reported former fires	0.00	0.42
		Jungle cleaning	0.11	0.40
		Reported former fires + Jungle cleaning	1.61	0.19
	Governmental/ historic activities	**EVI 2006** + EVI 1988	0.00	0.55
		EVI 1988 + EVI 2000 + **EVI 2006**	0.37	0.45
	Environmental factors	**Canopy cover** + ***Chromolaena* cover** + **Desirable species** + **Flooding** + **Nuisance species** + Overstory plant richness	0.00	0.08
		Canopy cover + ***Chromolaena* cover** + **Desirable species** + **Flooding** + **Nuisance species**	0.69	0.06
		Canopy cover + ***Chromolaena* cover** + **Desirable species** + **Flooding** + Understory plant richness + **Nuisance species** + Overstory plant richness	0.73	0.06
		Canopy cover + ***Chromolaena* cover** + **Desirable species** + **Flooding** + Elevation + **Nuisance species** + Overstory plant richness	0.82	0.06
		Canopy cover + ***Chromolaena* cover** + **Desirable species** + **Flooding** + **Nuisance species** + Road distance + Overstory plant richness	0.87	0.05

Ecosystem type	**Theoretical model set**	**Selected variables in model subsets**	**Delta AIC**	**Weight**
		Canopy cover + ***Chromolaena* cover** + **Desirable species** + River distance + **Flooding** + **Nuisance species**	1.02	0.05
		Canopy cover + ***Chromolaena* cover** + **Desirable species** + River distance + **Flooding** + **Nuisance species** + Overstory plant richness	1.18	0.05
		Canopy cover + ***Chromolaena* cover** + **Desirable species** + **Flooding** + Elevation + **Nuisance species** + Road distance + Overstory plant richness	1.29	0.04
		Canopy cover + ***Chromolaena* cover** + **Desirable species** + **Flooding** + Elevation + Understory plant richness + **Nuisance species** + Overstory plant richness	1.37	0.04
		Canopy cover + ***Chromolaena* cover** + **Desirable species** + **Flooding** + Understory plant richness + **Nuisance species**	1.57	0.04
		Canopy cover + ***Chromolaena* cover** + **Desirable species** + **Flooding** + **Nuisance species** + Road distance	1.61	0.04
		Canopy cover + ***Chromolaena* cover** + **Desirable species** + River distance + **Flooding** + **Nuisance species** + Road distance	1.62	0.04
		Canopy cover + ***Chromolaena* cover** + **Desirable species** + River distance + **Flooding** + Elevation + **Nuisance species** + Overstory plant richness	1.65	0.04
		Canopy cover + ***Chromolaena* cover** + **Desirable species** + River distance + **Flooding** + Elevation + **Nuisance species** + Road distance + Overstory plant richness	1.70	0.04
		Canopy cover + ***Chromolaena* cover** + **Desirable species** + Tree fall + **Flooding** + **Nuisance species** + Overstory plant richness	1.72	0.04
		Canopy cover + ***Chromolaena* cover** + **Desirable species** + River distance + **Flooding** + Elevation + **Nuisance species**	1.73	0.04

Ecosystem type	Theoretical model set	Selected variables in model subsets	Delta AIC	Weight
		Canopy cover + ***Chromolaena* cover** + **Desirable species** + **Flooding** + Understory plant richness + **Nuisance species** + Road distance + Overstory plant richness	1.76	0.04
		Canopy cover + ***Chromolaena* cover** + **Desirable species** + River distance + **Flooding** + Elevation + **Nuisance species** + Road distance	1.79	0.03
		Canopy cover + ***Chromolaena* cover** + **Desirable species** + River distance + **Flooding** + **Nuisance species** + Road distance + Overstory plant richness	1.81	0.03
		Canopy cover + ***Chromolaena* cover** + **Desirable species** + **Flooding** + **Nuisance species** + Slope + Overstory plant richness	1.82	0.03
		Canopy cover + ***Chromolaena* cover** + **Desirable species** + River distance + **Flooding** + Understory plant richness + **Nuisance species**	1.83	0.03
		Canopy cover + ***Chromolaena* cover** + **Desirable species** + **Flooding** + Elevation + **Nuisance species**	1.86	0.03
		Canopy cover + ***Chromolaena* cover** + **Desirable species** + River distance + **Flooding** + Understory plant richness + **Nuisance species** + Overstory plant richness	1.87	0.03
Dalbergia mixed forest	Individual activities	Evidence of cutting plants + Fodder + Picnic	0.00	0.12
		Fodder + Picnic	0.07	0.11
		Picnic	0.30	0.10
		Evidence of cutting plants + Picnic	0.40	0.10
		Firewood + Picnic	0.67	0.08
		Evidence of cutting plants + Firewood + Picnic	0.73	0.08
		Firewood	0.95	0.07
		Evidence of cutting plants	0.97	0.07
		Evidence of cutting plants + Firewood	1.22	0.06
		Fodder	1.53	0.05
		Evidence of cutting plants + Firewood + Fodder + Picnic	1.56	0.05
		Firewood + Fodder + Picnic	1.61	0.05
		Evidence of cutting plants + Fodder	1.78	0.05

Ecosystem type	Theoretical model set	Selected variables in model subsets	Delta AIC	Weight
	Collective activities	Jungle cleaning	0.00	0.40
		Reported former fires	0.26	0.35
		Reported former fires + Jungle cleaning	0.88	0.26
	Governmental/ historic activities	**EVI 2000** + EVI 2006	0.00	0.72
		EVI 2000 + EVI 2006 + EVI 1988	1.86	0.28
	Environmental factors	***Chromolaena* cover** + **Desirable species** + Flooding + **Understory richness** + **Lantana cover**+ **Nuisance species** + Overstory richness	0.00	0.10
		***Chromolaena* cover** + **Desirable species** + Flooding + **Understory richness** + **Lantana cover**+ **Nuisance species**	0.46	0.08
		***Chromolaena* cover** + **Desirable species** + Flooding + **Understory richness** + **Lantana cover**+ **Nuisance species** + Road distance + Overstory richness	0.57	0.08
		***Chromolaena* cover** + **Desirable species** + Flooding + **Understory richness** + **Lantana cover**+ **Nuisance species** + Slope + Overstory richness	0.74	0.07
		***Chromolaena* cover** + **Desirable species** + Flooding + **Understory richness** + **Lantana cover**+ **Nuisance species** + Road distance	0.95	0.07
		***Chromolaena* cover** + **Desirable species** + Fallen tree + Flooding + **Understory richness** + **Lantana cover**+ **Nuisance species** + Overstory richness	1.03	0.06
		***Chromolaena* cover** + **Desirable species** + Flooding + **Understory richness** + **Lantana cover**+ **Nuisance species** + Slope	1.05	0.06
		***Chromolaena* cover** + **Desirable species** + Fallen tree + Flooding + **Understory richness** + **Lantana cover**+ **Nuisance species** + Road distance + Overstory richness	1.26	0.06
		***Chromolaena* cover** + **Desirable species** + **Understory richness** + **Lantana cover**+ **Nuisance species**	1.42	0.05

Ecosystem type	Theoretical model set	Selected variables in model subsets	Delta AIC	Weight
		***Chromolaena* cover** + **Desirable species** + Flooding + **Understory richness** + **Lantana cover**+ **Nuisance species** + Road distance + Slope + Overstory richness	1.63	0.05
		***Chromolaena* cover** + **Desirable species** + Fallen tree + Flooding + **Understory richness** + **Lantana cover**+ **Nuisance species**	1.73	0.04
		***Chromolaena* cover** + **Desirable species** + Flooding + **Understory richness** + **Lantana cover**+ **Nuisance species** + Road distance + Slope	1.87	0.04
		***Chromolaena* cover** + **Desirable species** + Fallen tree + Flooding + **Understory richness** + **Lantana cover**+ **Nuisance species** + Road distance	1.92	0.04
		Canopy cover + ***Chromolaena* cover** + **Desirable species** + Flooding + **Understory richness** + **Lantana cover**+ **Nuisance species**	1.94	0.04
		***Chromolaena* cover** + **Desirable species** + **Understory richness** + **Lantana cover**+ **Nuisance species** + Slope	1.95	0.04
		***Chromolaena* cover** + **Desirable species** + Flooding + Elevation + **Understory richness** + **Lantana cover**+ **Nuisance species** + Overstory richness	1.96	0.04
		***Chromolaena* cover** + **Desirable species** + Fallen tree + Flooding + **Understory richness** + **Lantana cover**+ **Nuisance species** + Slope + Overstory richness	1.98	0.04
		Canopy cover + ***Chromolaena* cover** + **Desirable species** + Flooding + **Understory richness** + **Lantana cover**+ **Nuisance species** + Overstory richness	2.00	0.04
Shorea robusta forest	Individual activities	Firewood	0.00	0.22
		Evidence of plant cutting	0.51	0.17
		Evidence of plant cutting + Firewood	0.93	0.14
		Fodder	1.40	0.11
		Evidence of fire	1.51	0.10

Ecosystem type	**Theoretical model set**	**Selected variables in model subsets**	**Delta AIC**	**Weight**
		Picnic	1.66	0.10
		Firewood + Picnic	1.94	0.08
		Firewood + Fodder	1.97	0.08
	Collective activities	**Reported former fires**	0.00	0.73
		Reported former fires + Jungle cleaning	1.94	0.28
	Governmental/historic activities	EVI 2000 + EVI 2006 + EVI 1988	0.00	0.29
		EVI 2000 + EVI 2006	0.37	0.24
		EVI 1988	1.04	0.17
		EVI 2006 + EVI 1988	1.30	0.15
		EVI 2006	1.49	0.14
	Environmental factors	*Chromolaena* cover +**Nuisance species** +**Overstory richness**	0.00	0.18
		Chromolaena cover + River distance + **Nuisance species** + **Overstory richness**	0.72	0.13
		Chromolaena cover + Desirable species + **Nuisance species** + **Overstory richness**	0.73	0.13
		Chromolaena cover + Desirable species + River distance + **Nuisance species** + **Overstory richness**	1.02	0.11
		Chromolaena cover + Understory richness + **Nuisance species** + **Overstory richness**	1.18	0.10
		Nuisance species + **Overstory richness**	1.45	0.09
		Canopy cover + *Chromolaena* cover + **Nuisance species** + **Overstory richness**	1.94	0.07
		Chromolaena cover + **Nuisance species** + Slope + **Overstory richness**	1.97	0.07
		Chromolaena cover + **Nuisance species** + Road distance + **Overstory richness**	1.98	0.07
		Chromolaena cover + Fallen tree + **Nuisance species** + **Overstory richness**	2.00	0.07

Ecosystem type	**Theoretical model set**	**Selected variables in model subsets**	**Delta AIC**	**Weight**
Grassland	Individual activities	Evidence of fire	0.00	0.29
		Firewood	0.84	0.19
		Thatch	1.27	0.15
		Fodder	1.31	0.15
		Evidence of fire + Firewood	1.70	0.12
		Firewood + Fodder	1.96	0.11
	Collective activities	Reported former fires	0.00	0.73
		Reported former fires + Jungle cleaning	1.95	0.27
	Governmental/historic activities	EVI 2000	0.00	0.34
		EVI 1988	0.02	0.34
		EVI 2006	0.17	0.32
	Environmental factors	Elevation + **Understory richness**	0.00	0.25
		River distance + Elevation + **Understory richness**	1.26	0.13
		Desirable species + Elevation + **Understory richness**	1.37	0.13
		Understory richness	1.68	0.11
		Elevation + **Understory richness** + Road distance	1.93	0.10
		Elevation + **Understory richness** + Slope	1.94	0.10
		Canopy cover + Elevation + **Understory richness**	1.95	0.10
		Elevation + **Understory richness** + Nuisance species	1.96	0.09

APPENDIX G

STANDARDIZED BETA COEFFICIENTS OF AVERAGED SUBSET MODELS WITH THEIR ASSOCIATED P-VALUES.

The response variable is percent cover of *Mikania* abundance. Model-averages are only calculated for subset models with delta AIC < 2. NA indicates that the variable was not included in the averaged models because it occurred in less than 5% of the dataset. NS indicates that the variable was not selected because it was never present in subset models with a delta AIC <2.

			Subset Model-averages			
Ecosystem type	**Model**	**Predictor variable**	**Estimate**	**SE**	**p-value**	
All ecosystem types	Individual activities	Firewood collection (count)	-0.21	0.07	0.01	**
		Fodder collection (count)	0.21	0.07	<0.01	**
		Thatch collection (count)	NS	NS	NS	
		Medicinal plant collection (count)	NA	NA	NA	
		Grazing (count)	NA	NA	NA	
		Picnic/leisure (count)	0.07	0.07	0.31	
		Evidence of recent fire (count)	NS	NS	NS	
		Evidence of plant cutting (count)	-0.07	0.06	0.23	
	Collective activities	Jungle cleaning (count)	-0.15	0.06	0.01	*
		Grass plantations (count)	NA	NA	NA	
		Tree plantations (count)	NA	NA	NA	
		Reported former fires (count)	-0.68	0.07	<0.001	***
		Wetlands (count)	NA	NA	NA	
	Governmental/historic activities	EVI in year 1988	-0.32	0.07	<0.001	***
		EVI in year 2000	-0.29	0.07	<0.001	***
		EVI in year 2006	0.78	0.07	<0.001	***
	Environmental factors	Understory plant richness (count)	0.19	0.06	<0.001	***
		Overstory plant richness (count)	0.61	0.07	<0.001	***
		Canopy cover (%)	0.04	0.07	0.59	
		Chromolaena cover (%)	0.04	0.06	0.55	
		Lantana cover (%)	0.15	0.06	<0.01	**
		Presence of desirable species (count)	-0.55	0.06	<0.001	***
		Presence of nuisance species (count)	0.45	0.05	<0.001	***

			Subset Model-averages			
Ecosystem type	**Model**	**Predictor variable**	**Estimate**	**SE**	**p-value**	
		Elevation (meters)	-0.57	0.08	<0.001	***
		Slope (degrees)	0.07	0.05	0.15	
		Tree fall (count)	0.04	0.05	0.42	
		Evidence of flooding (count)	0.05	0.06	0.42	
		Road distance (meters)	NS	NS	NS	
		River distance in 2015 (meters)	-0.37	0.07	<0.001	***
Bombax mixed forest	Individual activities	Firewood collection (count)	0.14	0.06	0.03	*
		Fodder collection (count)	0.09	0.07	0.20	
		Thatch collection (count)	NS	NS	NS	
		Medicinal plant collection (count)	NA	NA	NA	
		Grazing (count)	NA	NA	NA	
		Picnic/leisure (count)	-0.02	0.07	0.73	
		Evidence of recent fire (count)	NA	NA	NA	
		Evidence of plant cutting (count)	-0.04	0.06	0.52	
	Collective activities	Jungle cleaning (count)	0.04	0.06	0.53	
		Grass plantations (count)	NA	NA	NA	
		Tree plantations (count)	NA	NA	NA	
		Reported former fires (count)	0.04	0.06	0.49	
		Wetlands (count)	NA	NA	NA	
	Governmental/historic activities	EVI in year 1988	-0.16	0.06	<0.01	**
		EVI in year 2000	-0.09	0.07	0.20	
		EVI in year 2006	0.68	0.07	<0.001	***
	Environmental factors	Understory plant richness (count)	0.06	0.06	0.26	
		Overstory plant richness (count)	-0.11	0.07	0.11	
		Canopy cover (%)	0.33	0.07	<0.001	***
		Chromolaena cover (%)	0.25	0.06	<0.001	***
		Lantana cover (%)	NS	NS	NS	

Ecosystem type	Model	Predictor variable	Subset Model-averages Estimate	SE	p-value	
		Presence of desirable species (count)	-0.27	0.07	<0.001	***
		Presence of nuisance species (count)	0.29	0.06	<0.001	***
		Elevation (meters)	-0.08	0.06	0.23	
		Slope (degrees)	-0.03	0.05	0.63	
		Tree fall (count)	0.03	0.05	0.57	
		Evidence of flooding (count)	-0.25	0.07	<0.001	***
		Road distance (meters)	-0.07	0.06	0.23	
		River distance in 2015 (meters)	-0.08	0.06	0.22	
Dalbergia mixed forest	Individual activities	Firewood collection (count)	-0.11	0.09	0.26	
		Fodder collection (count)	-0.13	0.10	0.18	
		Thatch collection (count)	NS	NS	NS	
		Medicinal plant collection (count)	NA	NA	NA	
		Grazing (count)	NA	NA	NA	
		Picnic/leisure (count)	0.15	0.09	0.11	
		Evidence of recent fire (count)	NA	NA	NA	
		Evidence of plant cutting (count)	-0.12	0.08	0.15	
	Collective activities	Jungle cleaning (count)	0.09	0.08	0.24	
		Grass plantations (count)	NA	NA	NA	
		Tree plantations (count)	NA	NA	NA	
		Reported former fires (count)	NA	NA	NA	
		Wetlands (count)	NA	NA	NA	
	Governmental/historic activities	EVI in year 1988	-0.05	0.11	0.67	
		EVI in year 2000	-0.40	0.15	<0.01	**
		EVI in year 2006	0.51	0.14	<0.001	***
	Environmental factors	Understory plant richness (count)	0.33	0.09	<0.001	***
		Overstory plant richness (count)	-0.14	0.09	0.12	
		Canopy cover (%)	-0.06	0.11	0.61	

Ecosystem type	Model	Predictor variable	Subset Model-averages			
			Estimate	SE	p-value	
		Chromolaena cover (%)	0.44	0.09	<0.001	***
		Lantana cover (%)	0.17	0.08	0.04	*
		Presence of desirable species (count)	-0.65	0.09	<0.001	***
		Presence of nuisance species (count)	0.19	0.08	0.01	**
		Elevation (meters)	-0.03	0.08	0.73	
		Slope (degrees)	0.08	0.07	0.26	
		Tree fall (count)	-0.08	0.07	0.30	
		Evidence of flooding (count)	-0.15	0.08	0.05	*
		Road distance (meters)	-0.09	0.08	0.21	
		River distance in 2015 (meters)	NS	NS	NS	
Shorea robusta forest	Individual activities	Firewood collection (count)	-0.42	0.31	0.17	
		Fodder collection (count)	-0.09	0.46	0.85	
		Thatch collection (count)	NA	NA	NA	
		Medicinal plant collection (count)	NA	NA	NA	
		Grazing (count)	NA	NA	NA	
		Picnic/leisure (count)	-0.02	0.35	0.96	
		Evidence of recent fire (count)	0.16	0.29	0.60	
		Evidence of plant cutting (count)	-0.37	0.30	0.21	
	Collective activities	Jungle cleaning (count)	-0.09	0.32	0.78	
		Grass plantations (count)	NA	NA	NA	
		Tree plantations (count)	NA	NA	NA	
		Reported former fires (count)	-0.83	0.34	0.02	*
		Wetlands (count)	NA	NA	NA	
	Governmental/historic activities	EVI in year 1988	-0.48	0.33	0.15	
		EVI in year 2000	-0.72	0.54	0.18	
		EVI in year 2006	0.50	0.37	0.18	
	Environmental factors	Understory plant richness (count)	-0.29	0.31	0.35	

Ecosystem type	Model	Predictor variable	Subset Model-averages			
			Estimate	**SE**	**p-value**	
		Overstory plant richness (count)	0.60	0.26	0.02	*
		Canopy cover (%)	-0.09	0.30	0.77	
		Chromolaena cover (%)	-0.90	0.45	0.05	*
		Lantana cover (%)	NA	NA	NA	
		Presence of desirable species (count)	-0.26	0.22	0.23	
		Presence of nuisance species (count)	NA	NA	NA	
		Elevation (meters)	NS	NS	NS	
		Slope (degrees)	0.06	0.25	0.81	
		Tree fall (count)	0.05	0.30	0.86	
		Evidence of flooding (count)	NA	NA	NA	
		Road distance (meters)	0.06	0.27	0.82	
		River distance in 2015 (meters)	0.28	0.23	0.22	
Grassland	Individual activities	Firewood collection (count)	0.05	0.07	0.49	
		Fodder collection (count)	-0.05	0.10	0.63	
		Thatch collection (count)	0.01	0.07	0.85	
		Medicinal plant collection (count)	NA	NA	NA	
		Grazing (count)	NA	NA	NA	
		Picnic/leisure (count)	NA	NA	NA	
		Evidence of recent fire (count)	-0.09	0.06	0.18	
		Evidence of plant cutting (count)	NA	NA	NA	
	Collective activities	Jungle cleaning (count)	0.05	0.29	0.87	
		Grass plantations (count)	NA	NA	NA	
		Tree plantations (count)	NA	NA	NA	
		Reported former fires (count)	NA	NA	NA	
		Wetlands (count)	NA	NA	NA	
	Governmental/historic activities	EVI in year 1988	0.16	0.33	0.62	
		EVI in year 2000	0.13	0.26	0.61	

			Subset Model-averages			
Ecosystem type	**Model**	**Predictor variable**	**Estimate**	**SE**	**p-value**	
		EVI in year 2006	0.10	0.31	0.75	
	Environmental factors	Understory plant richness (count)	0.60	0.31	0.05	*
		Overstory plant richness (count)	NA	NA	NA	
		Canopy cover (%)	0.51	1.48	0.73	
		Chromolaena cover (%)	NS	NS	NS	
		Lantana cover (%)	NA	NA	NA	
		Presence of desirable species (count)	-0.20	0.25	0.42	
		Presence of nuisance species (count)	0.12	0.33	0.73	
		Elevation (meters)	-0.74	0.37	0.05	*
		Slope (degrees)	0.10	0.28	0.72	
		Tree fall (count)	NA	NA	NA	
		Evidence of flooding (count)	NS	NS	NS	
		Road distance (meters)	-0.13	0.34	0.70	
		River distance in 2015 (meters)	-0.32	0.34	0.35	

Significance codes: <0.001 '***', <0.01 '**', <0.05 '*', <0.10 '--'

SE: standard error.

APPENDIX H

ITEMS CITED IN 25 FREE LISTS ABOUT PLANTS THAT ARE CONSIDERED HARMFUL OR INVASIVE IN COMMUNITY FORESTS OF NEPAL.

Items cited in 25 free lists about plants that are considered harmful or invasive in community forests of Nepal, followed by their salience index and mean rank order (position within the lists). Free lists were conducted across 25 interview groups. Salience values are represented as an index between 0 (not salient) and 1 (very salient). Frequency cited is measured as the percentage of lists (out of 25) where the plant was named. Mean position represents the overall rank that the plant held within a list (numbers closer to 1 indicate the plant was often listed earlier in the list).

Scientific name	Nepali plant name	Salience value	% Frequency cited	Number of citations (out of 25 groups)	Mean position (order in list)
Mikania micrantha	Lahare Banmara	0.89	100	25	1.60
Chromolaena odorata	Banmara	0.44	64	16	2.75
Ageratum spp.	Boke jhar (Gandhe)	0.36	52	13	2.46
Ageratum conyzoides	Gandhe (nilo)	0.21	24	6	1.83
Lantana camara	Banmara (Kande)	0.20	36	9	3.33
Ageratum houstonianum	Seto Gandhe	0.14	24	6	3.67
Parthenium hysterophorus	Gajar pate jhar	0.12	28	7	4.86
Urtica dioica	Sisnu	0.11	28	7	5.14
Cymbopogon winterianus spreng.	Citronella	0.10	24	6	4.33
Dicranopteris linearis (Burm)	Unyu	0.10	20	5	5.20
Solanum aculeatissimum (Jaca.)	Kantakari	0.08	16	4	4.75
Vallaris solanacea (Roth) Kuntze	Dudhe lahara	0.07	12	3	3.67
Ziziphus nummularia	Bayar	0.06	16	4	5.00
Mimosa pudica L.	Lajawati	0.05	12	3	5.67
Caesalpinia decapitala (Roth.) Alston	Areli kanda	0.04	8	2	3.50
Colebrookea oppositifolia sm.	Dhursilo	0.04	8	2	3.00
Tetrastigma serrulatum (Roxb.) Panch.	Charchare lahara	0.03	4	1	2.00
Cirsium arvense (L.) Scop.	Gaide Kanda	0.03	12	3	5.33
NA	Damre Kanda	0.03	4	1	3.00
Mucuna nigricans	Kauso	0.02	8	2	4.50
Senna tora (L.) Roxb.	Tapre	0.02	4	1	3.00
Urena lobata	Nalu kuro	0.02	4	1	6.00
Xeromphis spinosa (Thunb.) Reay	Main Kanda	0.01	4	1	5.00
Paedoria foetida L.	Pade jhar	0.01	4	1	8.00
Ageratina adenophora	Red stem	0.01	4	1	6.00
Xanthium strumarium L.	Vede kuro	0.01	4	1	7.00
Hyptis suaveolens	Bamari (Ban simal)	0.01	4	1	4.00

Scientific name	Nepali plant name	Salience value	% Frequency cited	Number of citations (out of 25 groups)	Mean position (order in list)
Commelina benghalensis L.	Kane jhar	0.01	4	1	9.00
Unidentified vine 1	Lahare (climbs on trees)	0.01	4	1	5.00
Unidentified vine 2	Jalifal	0.01	4	1	5.00
NA	Indreni	0.01	4	1	6.00
NA	Makre jhar (Jhuse Barulo)	0.01	4	1	6.00
Acmella oliginosa	Ban Marathi	0.00	4	1	10.00

APPENDIX I

FREQUENCY OF PLANT CITATIONS FOR EACH INTERVIEW CATEGORY.

Plants are sorted in order of their frequency (most to least) over all 25 interview groups. The items in bold are the plants that were targeted for removal in the adaptive method. The items marked by an asterisk indicate the plant was cited in each of the five interview categories: Women non-participants (5) , Men non-participants (5), Women participants (5), Men participants (5), and CF managers (5), though the plant may not have been listed in all 25 individual interview groups. Abbreviations NP (non-participant), P (participant), W (women), M (men), CF (community forest managers) indicate that the plants are only cited in those interview categories and do not occur in any other category.

			All categories	Women forest users			Men forest users			CF managers
Scientific name	Nepali plant name	Interview category	Overall (n=25)	Overall n=10	Participants n=5	Non-participants n=5	Overall n=10	Participants n=5	Non-participants n=5	Overall n=5
Mikania micrantha	**Lahare Banmara**	*	25	10	5	5	10	5	5	5
Chromolaena odorata	**Banmara**	*	16	6	4	2	6	5	1	4
Ageratum spp.	**Boke jhar (Gandhe)**	*	13	8	4	4	4	2	2	1
Lantana camara	**Banmara (Kande)**	*	9	5	4	1	2	1	1	2
Parthenium hysterophorus	**Gajar pate jhar**	W CF	7	3	1	2	0	0	0	4
Urtica dioica	Sisnu	*	7	4	1	3	2	1	1	1
Ageratum conyzoides	**Gandhe (nilo)**	*	6	2	1	1	2	1	1	2

			All categories	Women forest users			Men forest users			CF managers
Scientific name	Nepali plant name	Interview category	Overall (n=25)	Overall n=10	Participants n=5	Non-participants n=5	Overall n=10	Participants n=5	Non-participants n=5	Overall n=5
Cymbopogon winterianus spreng.	Citronella		6	2	1	1	1	1	0	3
Ageratum houstonianum	**Seto Gandhe**	*	6	2	1	1	2	1	1	2
Dicranopteris linearis (Burm)	Unyu		5	3	1	2	1	0	1	1
Solanum aculeatissimum (Jaca.)	Kantakari		4	3	1	2	1	0	1	0
Ziziphus nummularia	Bayar	M CF	4	0	0	0	3	1	2	1
Vallaris solanacea (Roth) Kuntze	Dudhe lahara	W CF	3	2	1	1	0	0	0	1
Mimosa pudica L.	Lajawati	W NP	3	3	0	3	0	0	0	0
Cirsium arvense (L.) Scop.	Gaide Kanda		3	2	1	1	1	1	0	0
Colebrookea oppositifolia sm.	Dhursilo	M	2	0	0	0	2	1	1	0
Mucuna nigricans	Kauso	M NP	2	0	0	0	2	0	2	0

				All categories	Women forest users			Men forest users			CF managers
Scientific name	Nepali plant name	Interview category		Overall (n=25)	Overall n=10	Participants n=5	Non-participants n=5	Overall n=10	Participants n=5	Non-participants n=5	Overall n=5
Caesalpinia decapitala (Roth.) Alston	Areli kanda	M	CF	2	0	0	0	1	0	1	1
Urena lobata	Nalu kuro		CF	1	0	0	0	0	0	0	1
Xanthium strumarium L.	Vede kuro		CF	1	0	0	0	0	0	0	1
Paedoria foetida L.	Pade jhar	W	NP	1	1	0	1	0	0	0	0
Commelina benghalensis L.	Kane jhar	W	NP	1	1	0	1	0	0	0	0
Acmella oliginosa	Ban Marathi	W	NP	1	1	0	1	0	0	0	0
Senna tora (L.) Roxb.	Tapre	W	NP	1	1	0	1	0	0	0	0
Unidentified vine 1	Lahare climbs on trees	M	NP	1	0	0	0	1	0	1	0
NA	Indreni		CF	1	0	0	0	0	0	0	1
Hyptis suaveolens	Bamari (Ban simal)	M	P	1	0	0	0	1	1	0	0

				All categories	Women forest users			Men forest users			CF managers
Scientific name	Nepali plant name	Interview category		Overall (n=25)	Overall n=10	Participants n=5	Non-participants n=5	Overall n=10	Participants n=5	Non-participants n=5	Overall n=5
Unidentified vine 2	Jalifal	M	NP	1	0	0	0	1	0	1	0
NA	Makre jhar (Jhuse Barulo)	W	P	1	1	1	0	0	0	0	0
Tetrastigma serrulatum (Roxb.) Panch.	Charchare lahara	M	NP	1	0	0	0	1	0	1	0
NA	Damre Kanda	M	NP	1	0	0	0	1	0	1	0
Xeromphis spinosa (Thunb.) Reay	Main Kanda	M	NP	1	0	0	0	1	0	1	0
Ageratina adenophora	Red stem	W	P	1	1	1	0	0	0	0	0

APPENDIX J

FREQUENCY OF CITATION, MEAN ORDER (POSITION IN LIST), AND PERCENT OF RESPONDENTS WHO CITED IMPORTANT FOREST PLANT SPECIES (REPORTED BY RESPONDENTS TO GROW IN THE FOREST AND HAVE IMPORTANCE TO THEIR LIVES) IN THE FREE LIST ACTIVITY.

For mean order (position in list), lower values were cited earlier in the free list activity than higher values, ranging from 1 to 65). Some respondents cited invasive plants as species that grow in the forest and have importance to their lives (highlighted in bold and included at the top of the list). Empty cells indicated unidentified scientific name.

Nepali plant name	**Scientific name**	**Number of citations**	**Mean order in list**	**Percent frequency cited (out of 31)**
Nilo gandhe	***Ageratum conyzoides (L.)***	**5**	**19.0**	**16.1**
Seto Gandhe	***Ageratum houstonianum***	**4**	**31.0**	**12.9**
Banmara	***Chromolaena odorata***	**3**	**21.7**	**9.7**
Lahare Banmara	***Mikania micrantha***	**3**	**20.7**	**9.7**
Simal	*Bombax cieba*	24	14.3	77.4
Sissau	*Dalbergia sissoo*	24	9.5	77.4
Sal	*Shorea robusta*	23	10.4	74.2
Bhellar	*Trewia nudiflora*	21	9.7	67.7
Kutmiro	*Litsea monopetala (Roxb.) Pers.*	18	11.2	58.1
Amara	*Phyllanthus emblica L.*	17	14.4	54.8
Kamuna	*Cleistocalyx operculatus*	15	19.8	48.4
Jamuna	*Syzygium cumini (L.) Skeels*	14	18.6	45.2
Kaniya	*Ficus semicordata Buch. - Ham ex Sm.*	14	15.4	45.2
Khayer	*Acacia catechu*	14	10.8	45.2
Rudilo	*Pogostemon benghalensis*	14	9.8	45.2
Dhai Kamla	*Callicarpa macrophylla (Vahl.)*	13	8.4	41.9
Khas	*Saccharum spontaneum*	13	21.9	41.9
Pidal/ Pindar	*Treweria nudiflora*	13	16.2	41.9
Aap	*Mangifera indica*	10	14.1	32.3
Bakenu	*Melia azederach L.*	10	14.7	32.3
Harro	*Terminalia chebula Retz*	10	9.8	32.3
Barro	*Terminalia bellirica (Gaertn.) Roxb.*	9	12.3	29.0
Siru	*Imperata cylindrica*	8	19.5	25.8
Dumbri	*Ficus racemosa L.*	7	17.7	22.6
Harchur	*Viscum album L.*	7	16.3	22.6
Kusum		7	22.1	22.6
Satisal		7	17.9	22.6
Bas	*Bambusa spp.*	6	9.8	19.4
Belauti	*Psidium guajava*	6	16.0	19.4
Gudar Gano	*Cissampelos pareira L.*	6	18.8	19.4
Kaagati	*Citrus L.*	6	24.5	19.4

Nepali plant name	Scientific name	Number of citations	Mean order in list	Percent frequency cited (out of 31)
Neem	*Azadirachta indica A. Juss*	6	22.7	19.4
Rohini		6	21.0	19.4
Saj		6	12.8	19.4
Bhatti	*Clerodendrum viscosum*	5	25.6	16.1
Bhayer	*Zizyphus numularia*	5	28.8	16.1
Gidari		5	21.6	16.1
Amba	*Psidium guajava L.*	4	24.0	12.9
Ambriso		4	35.3	12.9
Aru	*Prunus persica (L.) Batsch*	4	22.0	12.9
Asuro	*Justicia adhatoda L.*	4	18.5	12.9
Chatiwan		4	13.3	12.9
Dhursilo	*Callicarpa macrophylla Vahl*	4	14.3	12.9
Dubo	*Cynodon dactylon (L.) Pers.*	4	20.5	12.9
Gaye	*Bridelia retusa (L.)*	4	28.0	12.9
Goltabre		4	3.8	12.9
Kaphal	*Myrica esculenta Buch. -Ham. Ex D. Don*	4	22.8	12.9
Kuro	*Bidens biternata (Lour.) Merr and Sherff.*	4	20.8	12.9
Neuro	*Dryopteris cochleata (D. Don) C. Chr*	4	22.5	12.9
Pan - Jarda		4	14.8	12.9
Rajbrikshya	*Cassia fistula L.*	4	18.8	12.9
Sindure		4	12.8	12.9
Swami		4	21.5	12.9
Ticu/thinko		4	12.0	12.9
Tortne		4	16.8	12.9
Sisnu	*Urtica dioica*	4	14.3	12.9
Asare		3	9.3	9.7
Banso	*Eragrostis atrovirens (Desf.)*	3	24.0	9.7
Bar	*Ficus benghalensis L.*	3	15.7	9.7
Bardairo		3	27.0	9.7
Bel	*Aegle marmelos (L.)*	3	22.3	9.7
Chilaumi		3	18.3	9.7
Chini Jhar		3	21.0	9.7
Chitu		3	36.0	9.7
Dhairo		3	19.7	9.7
Dudhe		3	15.3	9.7
Dursilo	*Colebrookea oppositifolia (Sm.)*	3	10.7	9.7

Nepali plant name	Scientific name	Number of citations	Mean order in list	Percent frequency cited (out of 31)
Ipilipi		3	24.7	9.7
Kalikhat		3	19.7	9.7
Karang	*Caeselpinia decapetala (Roth) Alston*	3	12.3	9.7
Katahar (Rukh)		3	23.0	9.7
Keraa	*Musa paradisiaca L.*	3	16.0	9.7
Kursaani Ghas		3	44.7	9.7
Lemongrass	*Citronella spp.*	3	36.7	9.7
Nebuwa		3	30.7	9.7
Nimaro		3	30.7	9.7
Palash	*Butea monosperma (Lam.) Kuntze*	3	17.0	9.7
Sadhan		3	9.3	9.7
Sigane		3	15.7	9.7
Tanki		3	13.0	9.7
Thort Mari		3	27.7	9.7
Titepati	*Artemisia indica*	3	11.3	9.7
Aank		2	20.0	6.5
Abijalo	*Drymaria villosa*	2	25.0	6.5
Aiselu		2	15.0	6.5
Amaro	*Spondias pinnata (L.f.) Kurz*	2	29.0	6.5
Angur	*Vitis vinifera L.*	2	30.5	6.5
Ather		2	19.0	6.5
Ba		2	50.0	6.5
Badar		2	20.5	6.5
Batulo Pate	*Flemingia strobilifera (L.)*	2	18.5	6.5
Bhatulo Pate		2	4.0	6.5
Bhote		2	32.0	6.5
Brahmi	*Centella asiatica (L.) Urban.*	2	4.5	6.5
Bringaraj	*Alternanthera sessilis (L.) DC.*	2	8.0	6.5
Chulthe Lahare		2	11.5	6.5
Dairo		2	9.0	6.5
Darmarua		2	19.0	6.5
Dhaddi Ghas	*Themeda arundinacea (Roxb.) Ridley*	2	35.0	6.5
Dhatarunga		2	22.0	6.5
Dhayero		2	20.5	6.5
Gajo		2	27.0	6.5
Golmor		2	35.5	6.5

Nepali plant name	Scientific name	Number of citations	Mean order in list	Percent frequency cited (out of 31)
Guljolahara	*Tinospora cordifolia*	2	14.5	6.5
Hadikaule		2	9.0	6.5
Indra Jau	*Holarrhena pubescens*	2	32.5	6.5
Jharayamilo		2	13.0	6.5
Kaidel		2	26.5	6.5
Kaligade		2	8.0	6.5
Kane Ghas		2	18.0	6.5
Karam		2	13.5	6.5
Khalikhat		2	5.0	6.5
Khursani Ghas		2	17.0	6.5
Kutmiro	*Litsea monopetala (Roxb.) Pers.*	2	14.5	6.5
Laja Ote		2	12.5	6.5
Litchi		2	8.5	6.5
Mulapate	*Sonchus wightianus D.C.*	2	4.5	6.5
Narkot		2	16.5	6.5
Paiyo		2	32.0	6.5
Pakhete Unyu		2	26.0	6.5
Pate		2	28.0	6.5
Punarnavaha Raato		2	62.5	6.5
Sahadeb		2	54.5	6.5
Salla		2	6.0	6.5
Sami	*Ficus benjamina L.*	2	7.5	6.5
Sandan		2	24.0	6.5
Seto Musali		2	35.5	6.5
Shrikhanda		2	35.0	6.5
Sidarlo		2	46.0	6.5
Sidda		2	28.0	6.5
Sikhar Lahara		2	3.0	6.5
Sudikada		2	33.0	6.5
Tarul		2	37.5	6.5
Thirjo	*Aeschynanthus parviflorus*	2	17.0	6.5
Unyu		2	23.0	6.5
Uttis	*Desmotrichum fimbriatum Bl.*	2	22.0	6.5
Adil		1	50.0	3.2
Akh	*Calotropis gigantea (L.) Dryand.*	1	20.0	3.2
Amilo		1	40.0	3.2

Nepali plant name	Scientific name	Number of citations	Mean order in list	Percent frequency cited (out of 31)
Anikale jhar	*Crassocephalum crepidioides (Benth.)*	1	6.0	3.2
Apamarg	*Achyranthes aspera L.*	1	8.0	3.2
Argi		1	9.0	3.2
Aso ghanda		1	2.0	3.2
Babaiyo		1	31.0	3.2
Baichabo		1	45.0	3.2
Bajardanti		1	25.0	3.2
Ban Daune		1	16.0	3.2
Ban Tulesi		1	58.0	3.2
Bantori		1	28.0	3.2
Bardar		1	13.0	3.2
Baruwa	*Saccharum benghalensis (Retz.)*	1	16.0	3.2
Batra Ghanti	*Ludwigia hyssopifolia (G. Don) Exell*	1	11.0	3.2
Bed Ko Laharo		1	11.0	3.2
Bedulo		1	22.0	3.2
Bet	*Calamus acanthospathus*	1	23.0	3.2
Betlauri		1	5.0	3.2
Bhalaiyo		1	51.0	3.2
Bhamari		1	59.0	3.2
Bhorla		1	39.0	3.2
Bhui Katahar	*Ananas comosus (L.) Merr.*	1	23.0	3.2
Bijay Sal		1	38.0	3.2
Bikasee Kurilo		1	47.0	3.2
Bilauni		1	35.0	3.2
Birale Lahara		1	33.0	3.2
Bodo		1	14.0	3.2
Bohori		1	26.0	3.2
Bote		1	5.0	3.2
Buddhayara		1	22.0	3.2
Chaap		1	19.0	3.2
Chabo	*Piper mullesua*	1	16.0	3.2
Chariamili		1	53.0	3.2
Chathil		1	27.0	3.2
Chayau		1	51.0	3.2
Chilobatulopat		1	4.0	3.2
Chiraito		1	27.0	3.2

Nepali plant name	**Scientific name**	**Number of citations**	**Mean order in list**	**Percent frequency cited (out of 31)**
Chutro		1	12.0	3.2
Cilaune		1	36.0	3.2
Cyaau		1	23.0	3.2
Daam		1	21.0	3.2
Dabdabe		1	8.0	3.2
Daddhi Ghas		1	27.0	3.2
Dagera		1	25.0	3.2
Dammaru		1	34.0	3.2
Dari Githo		1	18.0	3.2
Datiwan	*Achyranthus aspera (L.)*	1	34.0	3.2
Dhamila		1	18.0	3.2
Dodhe Ghas		1	49.0	3.2
Dudhe pate		1	19.0	3.2
Dudhika Jhar		1	9.0	3.2
Dudhilo		1	33.0	3.2
Farsa Or Parsa	*Grewia sapida*	1	28.0	3.2
Gedula		1	4.0	3.2
Gheu Kumari		1	48.0	3.2
Ghoda	*Hemartheria compressa (L.f.)*	1	20.0	3.2
Golaichi		1	64.0	3.2
Gudugi		1	4.0	3.2
Habi		1	15.0	3.2
Hade Unyu		1	44.0	3.2
Hadkola		1	5.0	3.2
Jahne Lahara		1	10.0	3.2
Jakarisiaula		1	10.0	3.2
Jamile		1	24.0	3.2
Jhaki Buta		1	8.0	3.2
Jigot		1	18.0	3.2
Jire Khursani		1	38.0	3.2
Joge/I Kath		1	12.0	3.2
Kachha (Sandan)		1	26.0	3.2
Kadi Pata		1	13.0	3.2
Kahlo Musali		1	65.0	3.2
Kala Gira	*Nigella sativa L.*	1	29.0	3.2
Kalekhat	*Myrsine semiserrata Wall.*	1	11.0	3.2

Nepali plant name	Scientific name	Number of citations	Mean order in list	Percent frequency cited (out of 31)
Kali Sinki		1	42.0	3.2
Kalmek		1	3.0	3.2
Kalo Haledo		1	42.0	3.2
Kankarne		1	56.0	3.2
Kapur		1	21.0	3.2
Katus		1	30.0	3.2
Kaulikhat		1	24.0	3.2
Kauro		1	30.0	3.2
Khas / Dhade	*Themeda arundinacea*	1	12.0	3.2
Kode Bansu	*Paspalum scrobiculatum*	1	3.0	3.2
Koiral		1	6.0	3.2
Kukurdaine		1	10.0	3.2
Kut Simal		1	18.0	3.2
Lampate		1	3.0	3.2
Leruee		1	7.0	3.2
Mahanim		1	26.0	3.2
Maidala		1	31.0	3.2
Makhan		1	13.0	3.2
Maltato		1	27.0	3.2
Marich		1	37.0	3.2
Menta		1	50.0	3.2
Mewa	*Carica papaya L.*	1	55.0	3.2
Nanduke		1	28.0	3.2
Nas Ko Bot		1	12.0	3.2
Newara		1	30.0	3.2
Nundhike		1	7.0	3.2
Pahelo Haledo		1	44.0	3.2
Panaroj		1	8.0	3.2
Pandan		1	21.0	3.2
Pani Kutmira		1	10.0	3.2
Parijat	*Nyctanthes arbor-tristis L.*	1	22.0	3.2
Parsa Bute		1	26.0	3.2
Pathar Chata		1	13.0	3.2
Pati		1	18.0	3.2
Patina		1	49.0	3.2
Patla Neem		1	28.0	3.2

Nepali plant name	Scientific name	Number of citations	Mean order in list	Percent frequency cited (out of 31)
Peuli		1	40.0	3.2
Phader		1	33.0	3.2
Pharsa		1	63.0	3.2
Raato Sal		1	4.0	3.2
Rane Kusum		1	29.0	3.2
Rudrakchya		1	42.0	3.2
Rukh Katahar	*Artocarpus heterophyllus*	1	17.0	3.2
Sadiwan		1	33.0	3.2
Sapeta		1	13.0	3.2
Sarpaghanda		1	1.0	3.2
Seto Apamarga		1	61.0	3.2
Seto Haledo		1	43.0	3.2
Sikhare		1	10.0	3.2
Situnella		1	7.0	3.2
Starfruit		1	30.0	3.2
Sugar Jang		1	14.0	3.2
Tatari		1	15.0	3.2
Tejpata		1	19.0	3.2
Tharukath		1	29.0	3.2
Torigare / Tori	*Brassica napus*	1	9.0	3.2
Tulesi	*Ocimum tenuiflorum*	1	57.0	3.2
Tuni		1	20.0	3.2
Ugra Ganda		1	12.0	3.2
Ukhu	*Saccharum officinarum*	1	12.0	3.2
Aitanjhar		1	23.0	3.2

APPENDIX K

THE OVERALL RANK ORDER AND THE MEAN PREFERENCE RANK SCORE ± STANDARD DEVIATION IN PARENTHESES FOR EACH OF THE 26 DOMINANT FOREST PLANTS IN CFS VISITED BY RESPONDENTS.

Lower preference values are species that are preferred (respondents ranked these species early in their preference list). Bolded species are non-native and invasive. Asterisk to the right of the two categories (gender and ethnicity) indicates there is a significant difference in the species mean preference rankings between the social groups.

		--------------------Preference rank score ------------------------ (Mean ± SD)						
		----------Gender----------			---------Ethnic group--------			
Status	**Scientific name**	**Women**	**Men**		**Indigenous**	**First wave migrant**	**Second wave migrant**	
Native	*Shorea robusta*	1 (1.8 ± 1.5)	2 (5.3 ± 6.1)	*	1 (2.9 ± 3.1)	1 (3.8 ± 4.6)	1 (3.9 ± 6.2)	
Native	*Dalbergia sissoo*	2 (4.9 ± 3.6)	1 (5.3 ± 3.8)		2 (4.7 ± 3.2)	2 (6.3 ± 4.9)	2 (4.2 ± 2.5)	
Native	*Saccharum spontaneum*	3 (6.3 ± 3.4)	7 (8.2 ± 5.6)		6 (7.5 ± 5.0)	6 (7.8 ± 4.4)	3 (5.2 ± 5.0)	
Native	*Bombax ceiba*	4 (7.1 ± 5.6)	3 (6.1 ± 5.0)		3 (6.7 ± 5.2)	5 (7.8 ± 5.7)	4 (6.3 ± 4.8)	*
Native	*Imperata cylindrica*	5 (7.3 ± 3.8)	5 (7.1 ± 3.9)		4 (6.8 ± 4.7)	7 (8.5 ± 3.6)	5 (6.4 ± 2.8)	
Native	*Acacia catechu*	6 (8.3 ± 5.7)	4 (6.3 ± 4.4)		5 (7.3 ± 5.9)	4 (7.6 ± 4.3)	6 (7.2 ± 5.6)	
Native	*Cynodon dactylon*	7 (8.4 ± 4.6)	6 (8.1 ± 5.6)		9 (10.6 ± 6.3)	3 (6.3 ± 4.3)	7 (7.6 ± 3.2)	
Native	*Dryopteris cochleata*	8 (9.7 ± 4.1)	13 (12.1 ± 5.4)		11 (11.1 ± 3.5)	13 (12.9 ± 6.2)	8 (8.6 ± 4.1)	
Native	*Trewia nudiflora*	9 (10.2 ± 5.4)	12 (11.9 ± 6.0)		8 (10.2 ± 5.1)	14 (13.7 ± 7.5)	9 (9.2 ± 3.0)	
Native	*Litsea monopetala*	10 (10.4 ± 4.0)	14 (12.9 ± 6.0)		12 (11.5 ± 4.9)	12 (12.6 ± 5.0)	10 (9.9 ± 4.6)	
Native	*Piper longum*	11 (10.9 ± 6.6)	9 (9.8 ± 7.5)		7 (8.1 ± 4.6)	8 (9.3 ± 8.3)	11 (10.6 ± 5.7)	
Native	*Ziziphus nummularia*	12 (11.3 ± 3.9)	10 (10.3 ± 4.4)		10 (10.9 ± 4.9)	11 (10.9 ± 4.4)	12 (10.7 ± 3.2)	
Native	*Pogostemon benghalensis*	13 (12.1 ± 6.4)	8 (9.1 ± 5.8)		13 (11.9 ± 7.8)	9 (10.0 ± 6.2)	13 (13.1 ± 3.8)	
Native	*Colebrookea oppositifolia*	14 (13.1 ± 4.6)	16 (15.3 ± 7.0)		15 (12.8 ± 6.3)	17 (15.1 ± 6.5)	14 (13.9 ± 6.8)	
Native	*Urtica dioica*	15 (13.4 ± 4.7)	11 (10.8 ± 5.8)		14 (12.5 ± 5.5)	10 (10.8 ± 6.7)	15 (14.7 ± 5.1)	
Native	*Leersia hexandra*	16 (13.9 ± 5.6)	15 (15.2 ± 7.3)		17 (14.3 ± 8.5)	16 (14.5 ± 4.7)	16 (14.8 ± 6.0)	
Native	*Clerodendrum infortunatum*	17 (14.8 ± 4.0)	17 (15.5 ± 5.4)		16 (13.4 ± 4.3)	18 (15.2 ± 5.8)	17 (16.9 ± 3.3)	
Native	*Desmodium triflorum*	18 (17.3 ± 5.1)	18 (15.8 ± 7.0)		21 (15.9 ± 7.6)	15 (14.0 ± 5.3)	18 (19.7 ± 3.9)	

		--------------------Preference rank score ------------------------- (Mean ± SD)				
		----------Gender----------		---------Ethnic group--------		
Status	**Scientific name**	**Women**	**Men**	**Indigenous**	**First wave migrant**	**Second wave migrant**
Native	*Rungia pectinata*	19 (19.1 ± 5.6)	21 (18.9 ± 7.0)	22 (18.0 ± 9.0)	19 (18.3 ± 4.9)	19 (19.9 ± 3.0)
Invasive	***Ageratum houstonianum***	20 (19.7 ± 8.9)	23 (19.7 ± 7.2)	18 (14.8 ± 10.2)	26 (22.7 ± 4.1)	20 (20.2 ± 5.3)
Native	*Dicranopteris linearis*	21 (19.7 ± 6.6)	22 (19.6 ± 2.7)	23 (19.4 ± 7.4)	20 (18.8 ± 2.9)	21 (20.8 ± 3.0)
Invasive	***Ageratum conyzoides***	22 (19.8 ± 7.1)	19 (16.8 ± 7.9)	19 (14.9 ± 9.9)	21 (19.5 ± 6.7)	22 (20.8 ± 3.5)
Invasive	***Parthenium hysterophorus***	23 (20.3 ± 6.5)	20 (18.1 ± 6.5)	20 (15.4 ± 8.8)	22 (20.3 ± 3.8)	23 (20.9 ± 3.7)
Invasive	***Lantana camara***	24 (20.3 ± 5.7)	25 (20.6 ± 6.4)	24 (19.9 ± 7.1)	23 (20.4 ± 7.1)	24 (21.1 ± 3.2)
Invasive	***Mikania micrantha***	25 (20.6 ± 4.7)	26 (21.0 ± 4.1)	25 (20.4 ± 4.0)	24 (21.9 ± 3.9)	25 (22.0 ± 6.1)
Invasive	***Chromolaena odorata***	26 (21.8 ± 3.1)	24 (19.9 ± 4.6)	26 (20.9 ± 3.4)	25 (22.0 ± 4.5)	26 (22.4 ± 2.6)

APPENDIX L

CATEGORIZATION OF DOMINANT REFERENCE PLANTS.

The dominant reference plants (n=26) were categorized by respondents based on 5 general themes: Utility, Physical structure, Growth habit, Harm, and Unknown plant . We report the percent frequency of the generalized characterizations of each pile sort for each plant species from the reference plant list. A respondent could have more than theme in a pile characterization (e.g. *Ageratum conyzoides* could be in a pile referring to its use and the harm it causes. Thus, when all themes for a single species are summed, it could exceed 100%.

			Percent frequency of pile characterization				
Ecological status	**Scientific name**	**Nepali name**	**Utility**	**Physical structure (growth form)**	**Growth habit (seasonality or location)**	**Harm**	**Unknown plant**
Invasive	*Ageratum conyzoides*	Seto gandhe	86.7	20.0	0.0	6.7	3.3
Invasive	*Ageratum houstonianum*	Nilo gandhe	83.3	20.0	0.0	10.0	3.3
Invasive	*Chromolaena odorata*	Banmara	80.0	6.7	0.0	23.3	0.0
Invasive	*Lantana camara*	Banmara	70.0	13.3	3.3	20.0	3.3
Invasive	*Mikania micrantha*	Lahare banmara	76.7	16.7	3.3	26.7	0.0
Invasive	*Parthenium hysterophorus*	Gajar jhar	86.7	10.0	6.7	3.3	6.7
Native	*Acacia catechu*	Khayer	96.7	13.3	6.7	0.0	0.0
Native	*Bombax cieba*	Simal	93.3	20.0	10.0	0.0	0.0
Native	*Clerodendrum infortunatum*	Bhanti	93.3	10.0	3.3	0.0	0.0
Native	*Colebrookea oppositifolia*	Dhursilo	86.7	6.7	3.3	0.0	3.3
Native	*Cynodon dactylon*	Dubo	93.3	10.0	3.3	0.0	0.0
Native	*Dalbergia sissoo*	Sisau	93.3	16.7	6.7	0.0	0.0
Native	*Desmodium triflorum*	Chariamiliki mausi	83.3	20.0	16.7	0.0	10.0
Native	*Dicranopteris linearis*	Unyu	86.7	13.3	10.0	6.7	3.3
Native	*Dryopteris cochleata*	Niguro	90.0	13.3	10.0	0.0	0.0
Native	*Imperata cylindrica*	Siru	96.7	6.7	3.3	0.0	0.0
Native	*Leersia hexandra*	Karauti jhar	90.0	10.0	6.7	0.0	3.3
Native	*Litsea monopetala*	Kutmiro	100.0	6.7	3.3	0.0	0.0

			Percent frequency of pile characterization				
Ecological status	**Scientific name**	**Nepali name**	**Utility**	**Physical structure (growth form)**	**Growth habit (seasonality or location)**	**Harm**	**Unknown plant**
Native	*Piper longum*	Pipla	93.3	10.0	3.3	0.0	3.3
Native	*Pogostemon benghalensis*	Rudilo	90.0	13.3	3.3	0.0	3.3
Native	*Rungia pectinata*	Khursani jhar	83.3	16.7	10.0	3.3	10.0
Native	*Saccharum spontaneum*	Kans	100.0	6.7	6.7	0.0	0.0
Native	*Shorea robusta*	Saal	93.3	20.0	10.0	0.0	0.0
Native	*Treweria nudiflora*	Bhellar	96.7	16.7	10.0	0.0	0.0
Native	*Urtica dioica*	Sisnu	90.0	10.0	0.0	13.3	0.0
Native	*Ziziphus nummularia*	Bayar	96.7	10.0	6.7	0.0	0.0

APPENDIX M

PERCENTAGE OF RESPONDENTS WHO USE THE DOMINANT REFERENCE PLANTS.

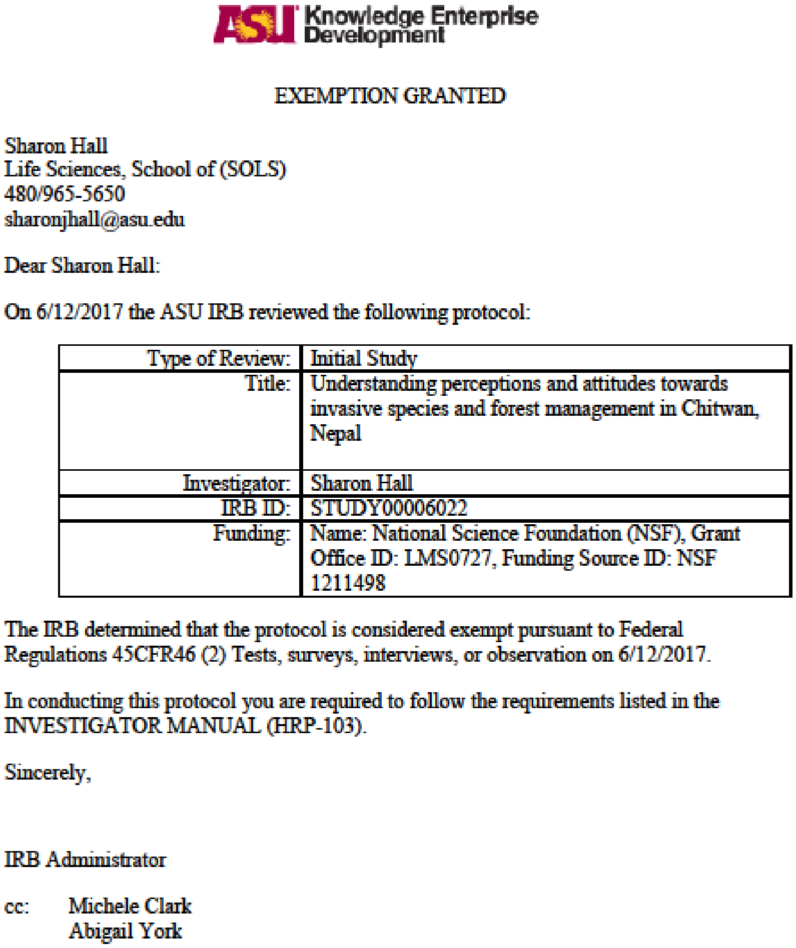
Percentage of respondents that report personally using the 26 dominant reference plants in some way and the percentage of respondents that reported a desire to alter the abundance of plants in the forest (increase, decrease, or remain the same). Invasive plants are in bold. All respondents answered questions about plant use, but only some respondents answered questions about wanting plants to increase or decrease (last column shows how many respondents answered the question).

	Respondent (themselves) use the plant in some way (% reported):						Within the forest, would you want the abundance of this plant species to (% reported):			
Scientific name	Overall (out of 30)	Indigenous (out of 10)	First wave migrant (out of 10)	Second wave migrant (out of 10)	Women (out of 15)	Men (out of 15)	Increase (out of 30)	Decrease	Remain the same	Responses
Ageratum conyzoides	47	70	30	40	33	60	23	70	3	29
Ageratum houstonianum	37	70	30	10	40	33	17	80	0	29
Chromolaena odorata	43	40	30	50	40	40	23	77	0	30
Lantana camara	40	20	50	40	27	47	23	63	7	28
Mikania micrantha	47	40	50	50	40	53	23	73	0	29
Parthenium hysterophorus	27	40	30	10	27	27	40	53	3	29
Acacia catechu	97	100	90	100	93	100	73	0	3	23
Bombax cieba	93	90	90	90	87	93	67	0	3	21
Clerodendrum infortunatum	87	100	80	70	73	93	23	0	17	12
Colebrookea oppositifolia	90	90	80	90	87	87	27	3	7	11
Cynodon dactylon	100	100	90	100	93	100	50	0	3	16
Dalbergia sissoo	100	100	90	100	93	100	77	0	0	23
Desmodium triflorum	60	50	60	60	47	67	30	13	7	15
Dicranopteris linearis	30	10	50	30	13	47	20	43	13	23

	Respondent (themselves) use the plant in some way (% reported):						Within the forest, would you want the abundance of this plant species to (% reported):			
Scientific name	Overall (out of 30)	Indigenous (out of 10)	First wave migrant (out of 10)	Second wave migrant (out of 10)	Women (out of 15)	Men (out of 15)	Increase	Decrease	Remain the same	Responses
							(out of 30)			
Dryopteris cochleata	100	100	100	100	100	100	30	0	7	11
Imperata cylindrica	100	100	100	100	100	100	47	0	7	16
Leersia hexandra	63	70	90	30	67	60	10	20	10	12
Litsea monopetala	100	100	100	90	100	93	30	0	10	12
Piper longum	73	100	70	40	60	80	60	3	3	20
Pogostemon benghalensis	97	90	90	100	93	93	37	0	13	15
Rungia pectinata	33	20	60	20	33	33	37	17	7	18
Saccharum spontaneum	100	100	90	100	93	100	50	0	7	17
Shorea robusta	100	100	90	100	93	100	90	0	0	27
Treweria nudiflora	100	100	90	100	93	100	37	3	7	14
Urtica dioica	73	90	70	50	60	80	40	10	3	16
Ziziphus nummularia	100	100	90	100	93	100	27	3	7	11

APPENDIX N

INSTITUTIONAL REVIEW BOARD EXEMPTION



Knowledge Enterprise Development

EXEMPTION GRANTED

Sharon Hall
Life Sciences, School of (SOLS)
480/965-5650
sharonjhall@asu.edu

Dear Sharon Hall:

On 6/12/2017 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	Understanding perceptions and attitudes towards invasive species and forest management in Chitwan, Nepal
Investigator:	Sharon Hall
IRB ID:	STUDY00006022
Funding:	Name: National Science Foundation (NSF), Grant Office ID: LMS0727, Funding Source ID: NSF 1211498

The IRB determined that the protocol is considered exempt pursuant to Federal Regulations 45CFR46 (2) Tests, surveys, interviews, or observation on 6/12/2017.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,

IRB Administrator

cc: Michele Clark
Abigail York