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Ungulate impact on forest naturalness and non-native invasive plant species

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Abstract

While some ungulate species are endangered, others are growing large populations. This increase in number for native and invasive ungulates can lead to large impact on the ecosystems from the plant scale to the community level. When selectivity is the most effective way for ungulates to alter the ecosystem composition and structure, ungulates can have more types of relations that can cause positive or negative impacts on plants communities including none-native plant species. In this systematic literature review our purpose was to investigate the relation between ungulates and non-native plants in forest ecosystems. Our aim was to answer these questions: 1) Are ungulates selecting non-native woody species? ; 2) Do the non-native plants have any kind of effect on ungulates? ; 3) What is the impact of the ungulates on non-native species in forest ecosystem? We found that: ungulates are selecting non-native species in 60% of the cases. The different methods used in these studies and the different plant species can show the complicity of this relation. The impact of non-native species on ungulates on the other hand was positive in 60% of the studies. These positive impacts can be categorized to dietary shift, habitat enhancement, reproduction enhancement and population increase, while the negative impacts were 40% and we could categorize them to habitat degradation, population decrease, and food scarcity. Finally, the ungulate impact on the non-native species was of different types mainly positive; direct facilitation with suppression of natives and seed dispersal were the main causes for the positive impact. The negative impact (hindrance) was limited to consuming the plants by the animal. The third type of impact was species-specific. In this type of impact, the relationship between ungulates and non-native plants is studied at the individual level. The impact is focused on specific plant species and can result in negative, positive, or no impact depending on factors related to the targeted plant. From these results, we can conclude that the relationship between ungulates and non-native plants is mixed (positive/negative) depending on different types of factors. Understanding the type of these relations is important in forest and wildlife management.

1. Introduction

The world currently experiencing a conservation crisis, including the endangerment and the rapid decrease of several ungulate species (World Wildlife Fund, 2020) such as the African rhino species, Saiga antelope (*Saiga tatarica*) in Asia, and the huemul (*Hippocamelus bisulcus*) in South America. This is largely attributed to human exploitation and its negative impact on these species. In contrast, populations of many ungulate species have dramatically risen as a result of human landscape modifications, predator eradication, and ecosystem trophic degradation (Estes et al., 2011). Furthermore, exotic ungulate species frequently grow considerable populations, such as deer species (red, fallow, sambar, rusa, chital, and hog deer) introduced in Australia (Moriarty, 2004), exotics large mammals introduced in North America (Teer, 2003), and various ungulates of Asian and North-American deer in Europe (Fuller & Gill, 2001).

Native and invasive large herbivores can affect the plant community composition (Côté et al., 2004) both, negatively by decreasing the variety and composition of the ecosystem (Didion, 2009, Sankaran 2013) and in positive way by increasing the variety (Faison, 2016, Beguin, 2011). Large herbivores can have a significant impact on plant communities in the forest ecosystem, from single plants to the landscape scale (Fowler, 2004). They can alter interspecific plant competition through selective herbivory. Large mammals' indirect herbivory is considered to be one of the most extensive impacts on vegetation structure (Crawley, 1997). Selective ungulate herbivory causes ecosystems to be dominated by unpalatable, chemically protected plant species (Augustine and McNaughton, 1998).

It has been observed that natural generalist herbivores minimize plant invasion by preferentially consuming foreign species over native plants (Parker et al., 2006) what is known as the biotic resistance hypothesis (BRH; Elton, 1958; Levine et al., 2004). Several studies showed that large mammals may hinder the invasion of some non-native species supporting the BRH (Rossell et al., 2007; Roy et al., 2017; Stromayer et al., 1998) but generalist herbivores may also have a more facilitative effect than the detrimental influence on exotic plant abundance (Maron & Vilà, 2001). These herbivores are known to disperse exotic seeds (Forsyth & Davis, 2011; Guiden et al., 2015; Williams & Ward, 2006; Williams et al., 2008). Several studies suggested that non-native plants have the potential to impact native plants through apparent competition. This is achieved by offering high-quality food when it is scarce, which can lead to reduction in winter malnutrition and increase in the carrying capacity of herbivore population (Wright et al., 2019; Juliá & Peris, 2010; Stromayer et al., 1998). On the other hand, their indirect role in favoring native over non-native plants (Ramirez et al., 2012; Nuñez et al., 2008; Moe et al., 2016) allows the invasive species to escape the native enemies and lends support to the enemy release hypothesis (ERH; Carpenter & Cappuccino, 2005). In addition, some researchers supported both of the hypotheses at the same time (Knapp et al., 2008; Kristine et al., 2018; Erickson et al., 2017; Shen et al., 2016). These findings show that herbivore impacts on plant invaders are dependent on plant species. All of the controversies surrounding the topic piqued the researchers' interest in understanding the interactions between ungulate and non- native plant species, as such understanding can help with: 1) planting ornamental or commercial exotic plants as means of mitigating the effects of climate change (Katona et al., 2013); 2) can provide an option for restoration after wildfires (Hunter et al, 2006) 3) understanding how invasive species affect the biodiversity (Hapca, 2011); 4) in addition to forecasting, preventing, and minimizing the detrimental impacts of biological invasions into new areas (Parker et al., 2006).

Due to the growing importance and to better understand the relation between ungulates and non-native plant species in forest ecosystems, we conducted a qualitative systematic literature review and tried to answer these questions:

- Are ungulates selecting non-native woody species?
- Do the non-native plants have any kind of effect on ungulates?
- What is the impact of the ungulates on non-native species in forest ecosystems?

2. Literature review

1.2 Non-native plant species and their impact on forest ecosystem

A non-native species is an animal, plant or any other organism transferred, either intentionally or unintentionally, beyond its original geographical and biological borders to a new country or location where it settles and adapts itself (Richardson et al, 2011). Not all well-established non-native species can cause harm to the ecosystem (Vilà et al., 2010) while invasive species which are defined as non-native introduced species, can distribute fast and cause harm to ecology, economy, and human health (Ricciardi, 2013). For example, Japanese knotweed (*Fallopia japonica*) causes detrimental impacts on the ecosystem by having the ability to form dense and thick stands. Those impacts can reduce the diversity, decrease the native plants and invertebrate abundance, change the nutrients cycle, and hinder the natural flow of water which can impact the flood protection system and cause erosion of riverbanks (Mark et al., 2018). The poison hemlock (*Conium maculatum*) is an invasive species recognized for its poisonous features to animals and humans together. Because it contains a neurotoxin in its seeds, stems, and leaves that can cause respiratory paralysis or even death in case of ingestion. Furthermore, it can cause skin irritation and allergies in some individuals (Vetter et al., 2004). From an economic point of view, the spotted lanternfly (*Lycorma delicatula*) caused an economic loss estimated at approximately 324 million dollars in 2019 (the University of Illinois Extension, 2021). While Kudzu (*Pueraria montana var. lobata)* due to its sharp impacts on infrastructure, agriculture, and forestry, costs over 500 million dollars per year in the United States of America (National Park Service, 2020). And in the United Kingdom, the cost of managing *Fallopia japonica* was estimated at more than 166 million dollars per year (BBC News, 2021).

Non-native species have both negative and positive impacts on forest ecosystems. Like providing essential ecosystem services such as carbon sequestration (Du et al., 2015) and some can play an important commercial role (Sitzia et al., 2016). While other non-native species can harm the function of the ecosystem and biodiversity (Vilà et al., 2010). One positive aspect of non-native plant species is their role in storing carbon. For instance, a study conducted in China revealed that the non-native tree Eucalyptus plays an important role in carbon sequestration, providing a significant ecological function to the environment (Du et al., 2015). In addition, non-native species in degraded regions can help in stabilizing the soil, preventing erosion, and promoting soil quality. (Wittenberg & Cock, 2001). An example of the commercial importance of non-native plants in Europe is the widespread use of Black locust (*Robinia pseudo acacia*), which originated from North America. The wood of the black locust is strong and resistant to mechanical stressors more over its suitable for biomass production because its rapid growth rate, the honey produced from this tree is high quality with fragrant aroma, and some people use the blossoms as a cooking ingredient (Sitzia et al., 2016). Its function in adjusting forest management practices to climate change is also crucial (Katona et al., 2013).

However,in forest ecosystems,the negative effects of non-native plant species can be significant non-native woody trees such as *Prunus serotina*, *Ailanthus altissima*, *Pseudotsuga menziesii*,*Eucalyptus globulus*,*Acacia dealbata*, *Quercus rubra*, *Robinia pseudoacacia* in Europe can negatively affect the biodiversity, specifically on orthopods and vascular plants (Wohlgemuth et al., 2022).

Overall, efficient management plans are essential for invasive and non-native plant species in forest ecosystems because non-native plant species have both positive and negative impacts on the forest ecosystem. Ungulate may play an important role in the success or failure of invasive and non-native plant species. They play a crucial role in altering the structure and diversity of the plant community in forest ecosystems. (Reimoser & Gossow, 1996; Stokely et al., 2020).

2.2 Ungulates and their role in the ecosystem

Ungulates are a divergent group of animals, distributed all over the world except for Antarctica. They are illustrated by their herbivore diet and hoofed feet. They vary between tiny mouse deer of Southeast Asia to the massive moose of North America. Taxonomically they are divided into two groups: the odd-toed ungulates (Order Perissodactyla), which include horses, rhinoceroses, and tapirs, and the even-toed ungulates (Order Artiodactyla), which include deer, antelope, bovids, and pigs (Groves et al., 2011; Prothero, 2001). Ungulates are characterized by some features that made them well adapted to the herbivore diet like four-chambered stomachs in several species and specialized teeth to grind the tough plant materials (Stevens & Hume, 2004). In addition to this physical adaptation, they have some distinctive social behaviors like territoriality, living in a group…etc. (Estes, 1991). This diversity in physical and social characteristics made them adapt to live in different types of habitats and ecosystems including forest ecosystems. Understanding their biology and ecology is crucial for managing and conserving these animals and the habitats they depend on (Ramirez et al., 2018). Ungulates play a crucial role in shaping the plant communities of forest ecosystems, with their browsing having both positive and negative impacts. Boulanger et al. (2018) found that the presence of wild ungulates in forest ecosystems has both positive and negative impacts on plant community characteristics. On the positive side, their presence contributes to higher species richness in the herbaceous layer and a more light-demanding environment. However, on the negative side, the ungulates leads to decrease in shrub cover and changes in plant community towards light demanding species, resulting in biotic homogenization and a conservation issue for plant community composition. Likewise, Faison (2016) notes that browsing by ungulates can have compensatory or additive effects on the diversity and composition of the herbaceous layer, and moderate browsing in forest openings can even boost the variety of herbaceous and woody plants. and Vild et al. (2017) also found that high ungulate density led to an increase in plant species richness, particularly by ruderal species, due to frequent disturbances and ungulate-mediated dispersal, but non-ruderal species richness remained unchanged as ungulates kept the forest canopy open and prevented the regrowth of woody plants.

However, Beguin's (2011) research has found that deer browsing and soil disturbance can have complex and interconnected effects on flora abundance, leading to a complex chain of cascading effects that can result in increased herbaceous richness. Didion's (2009) study showed that ungulate herbivory in forest stands can lead to significant changes in both the composition and structure of the forest, highlighting the importance of considering the impact of ungulate browsing in forest management. Sankaran (2013) also found that while small-bodied ungulates can hinder woody recruitment, browsing by medium and large-bodied ungulates can decrease the development and survival of individuals in larger-size classes. Therefore, it is important to understand the complex and varied impacts of ungulate browsing in forest ecosystems.

Several studies have explored the selectivity and preference of ungulates in forest ecosystems, and the impact of management practices on their browsing behavior. A study by Putman & Moore (1998) found that ungulates exhibit a strong preference for foraging in forest gaps, which can result in uneven browsing behavior and potentially significant damage in areas with high population density. One other study by Augustine & McNaughton (1998) found that selective browsing by ungulates can lead to changes in plant community structure, with highly palatable species being preferentially consumed and unpalatable species becoming dominant. However, nutrient inputs and foraging selectivity limitations can also maintain the dominance of highly palatable species. Another study by Roony & Waller (2003) found that ungulates, particularly white-tailed deer, have a profound impact on forest communities by directly limiting the regeneration of favored and susceptible woody and herbaceous plants, and indirectly affecting many other plant and animal populations through trophic cascades and physical habitat modification. Likewise, Fehér & Katona (2016) found that ungulate debarking is a selective natural disturbance that primarily targets certain tree species and smaller stems, and maintaining a diverse forest composition can reduce damage to major tree species of economic importance.

On the other hand, studies on the impact of ungulate population density on forest regeneration, structure, and functioning have shown that high density can have negative effects. A systematic literature review by Ramirez et al. (2018) found that in temperate forests, ungulate density has a harmful impact on forest regeneration, composition, and operation, with critical tipping points at approximately 10-23 Roe deer/km². Furthermore, high ungulate population can hinder the establishment of woody species and maintain gaps in the forest cover, leading to a decrease in non-ruderal species richness (Vild et al., 2017).

Management practices in forest ecosystems can also impact ungulate browsing behavior and the effects on forest structure and biodiversity. A study by Kuijper et al. (2009) found that forest management, particularly clear-cutting and subsequent reforestation, can create appealing foraging areas for ungulates, resulting in significant damage. However, the impact of forest management on tree regeneration was found to be significantly greater than that of ungulate browsing and grazing (Kramer et al., 2006).

As a result, ungulates can contribute to forest ecosystems by increasing species numbers and creating more open habitats. However, if there are many of them and they avoid unpalatable, chemically-defended vegetation, they can be detrimental to the ecosystem. As a result, management practices should be implemented following ungulate browsing behavior and population density. This will preserve forest ecosystem structure and biodiversity.

In addition, ungulates can also impact the growth and spread of non-native plant species in forest ecosystems. For instance, Relva et al. (2010) examined the meltdown hypothesis, which posits that invasive species can facilitate the success of other invasive species through positive feedback mechanisms, in the indigenous forest of Patagonia Argentina. The study found that introduced deer reduced the cover of native plants and facilitated the invasion of non-native tree species, indicating evidence of invasion meltdown. Similarly, Ramirez et al. (2012) studied the effects of mule deer browsing on post-fire resprouts in California and found that browsing reduced the canopy coverage of dominant shrub species by more than 93%. This led to a shift towards less palatable sage scrub species as well as non-native grasses and forbs. The study suggests that invasive deer can diminish the post-fire resilience of native shrub communities. Another study by De Jager et al. (2013) investigated the impact of flooding and deer browsing on floodplain forest recruitment. The study found that tree mortality increased with a high rate of deer browsing and long flood duration, leading to a shift in vegetation towards flood-tolerant and less-preferred plant species. Additionally, some plots were colonized by invasive plants.

Collectively, these investigations indicate that non-native deer can affect native vegetation by aiding the spread of non-native plant species and changing the make-up of native woodlands and shrubbery through their selective browsing habits. These impacts may have unfavorable repercussions for the functioning of ecosystems and initiatives for biodiversity preservation.

Studies have been conducted to analyze the relationship between deer browsing and other factors impacting forest ecosystems. Fisichelli and Miller (2018) concluded that deer browsing is a major factor in the presence of non-native plant species, although it may be affected by elements like bird-mediated dispersal. It was also determined that deer browsing can be used to restrict the spread of invasive species, as bushes grew 30 times faster in sections that were closed off from deer. In contrast, Shelton et al. (2011) investigated the effects of white-tailed deer on plants, animals, and mycorrhizal fungi in soils. It was found that deer browsing may affect mycorrhizal fungi and soil characteristics by changing the composition and number of understory plant species. The results of both studies demonstrate the intricate nature of the interactions between browsing and other stressors in forest ecosystems and advocate for management strategies that encompass multiple stressors to protect forest biodiversity.

The effects of deer browsing on the spread of plants appears to be largely dependent on the preferences of their diet. Generally, deer favor native plants over newly introduced ones, yet what they select to eat may vary greatly between species. Some foreign species are ignored by deer, while some are actively sought out. It appears that each species' reaction to non-native plants is an individual one, and that herbivore selectivity could be a significant factor in determining whether plant invasions succeed or fail. Native plant species are harmed by deer foraging on vegetation, although non-native plants are not affected much by it. This could lead to an alteration in the composition of the forest with native American beech in Washington (USA) (Rossell et al., 2007) becoming the dominant species. On a species level, deer browsing did not affect the type of non-native plants, but it did generally reduce the presence of Oriental bittersweet (*Celastrus orbiculatus*), revealing that deer could control this intrusive plant in a forest interior, specifically when it is found in small numbers (Rossell et al., 2007). Similarly, an investigation at a regional scale found that deer had both positive and negative impacts on non-native plant species. For example, tree-of-heaven and garlic mustard was facilitated by the deer browsing, while Japanese stilt-grass and shrubs like *Lonicera* and *Rosa* were suppressed in deer exclosures (Averill et al., 2018). According to Erickson et al. (2017), it looks like the white-tailed deer in the research displayed an inclination towards certain plants, consuming a higher amount of certain species than their natural occurrence in the environment, and at the same time eating less of other species, possibly helping in the proliferation of invasive plants like *Alliaria petiolata*. Besides, the study also discovered that some exotic plants, like *Lonicera* sp., *Elaeagnus* sp., *Rosa multiflora*,and *Rubus phoenicolasius*, were more prevalent in the fecal samples than in the plot samples, whilst some were hardly seen in the feces but high numbers in the plots, implying that the deer's foraging behavior may be promoting the spread of certain non-native plant species (Erickson et al., 2017). Using a long-term deer exclosure experiment a case study investigated the deer browsing impact on four non-native plant species abundance. the study found that deer browsing facilitates the invasion of numerous non-native species except *Rosa multiflora*. And those findings highlighted that the deer impact is species-specific as various species have different responses to deer browsing (Shen et al., 2016).

As well as, the key factor in determining the deer's impact on the invasion process was the deer's preference for some plant species over other plants (Averill et al., 2016). These findings suggest that herbivore selectivity may may impact a plant's ability to succeed or fail, because some invasive introduced plants, such as *Alliaria petiolata*, *Berberis thunbergii*, and *Microstegium vimineum*, were consistently avoided by deer, while others, such as *Celastrus orbiculatus*, *Ligustrum vulgare*, and *Lonicera morrowii*, were preferred (Averill et al., 2016).

2.3 Theoretical framework

This interaction between invasive plant species and herbivores is responsible for increasing the homogeneity of native plants community (Shen et al. 2016). Numerous research studies have suggested that the relationship between these two stressors (invasive plants and herbivores), is complex and often contradictory. On the one hand, herbivores can exert biotic resistance which reduces the impact of invasive species, on the other hand, invasive species may benefit from a phenomenon called enemy release, where they experience less predation or herbivory in their non-native range (Maron & Vilà, 2001). According to the enemy release hypothesis, the species in their distribution range have two types of enemy specialists and generalists. Without their specialist enemies, the invaders will trade chemical and physical defenses for growth and reproduction when transported into a new environment. leading to success in the invasion process. (Ayub & Oduor, 2022). Kalisz et al. (2014) studied the impact of enemy release by white-tailed deer on invasive plant species (garlic mustard) and native one (*Trillium*). As a result of the deer exclusion, the exotic was suppressed and the native flourished. Another study examined the trade-off between defensive equipment and growth rate by comparing the thorn structure in *Ulex europaeus* in both native (Spain) and invasion range (Chile). Following ERH, the invasive plants invested more mass in the thorns, but the thrones were less fibrous and easy to bend and seedlings showed more diameter growth and less thorns density , while the native plants throne became harder and less palatable for their enemy   (Medina et al, 2022).

The biotic resistance hypothesis explains why some invasive species fail to invade new ecosystems, where biodiversity (competition, herbivory, and native species) act as a barrier to invasion (Ricciardi, 2013). This hypothesis is related to how Elton(1958) defines the ecological niche; according to Elton, the niche is an environmental feature (related to the environment, not the species itself). In this case, the ecosystem contains vacant niches, and the number of vacant niches depends on biodiversity richness. Higher biodiversity ecosystems have few vacant niches, so invasive plants have no place to occupy. Although this hypothesis highlighted the importance of competition between native and non-native species, it neglected the(The richer get the rich concept positive interaction between species as a result of habitat modifiers diverting the environment, making it suitable for different species' survival) means that there is a possibility that the BRH could be abandoned as it ignores the characteristics of non-native species (interacting with their new environment), emphasizes competition, and neglects mutualism at the same time (Heger and Jeschke, 2018). According to this theory, native herbivores can limit the invasive species population only when the invasive population is under a certain threshold (Maron & Vilà, 2001). And there are additional two issues that contradict the biotic resistant hypothesis the first one is seed dispersal when ungulates feed on the seeds of the non-native species aiding their distribution, and the second issue is the ELP theory and the apparent competition.

The ELP theory means that the extended leaf phenology of invasive plant species is thought to provide them an advantage over native plant species because it permits them to access light and obtain carbon at critical times in the spring and fall. Moreover, invasive plants that are sensitive to native herbivores can have a major influence on these herbivores' population dynamics. This is because invasive plants supply high-quality food at a time when it is generally limited, potentially lowering the danger of winter hunger and enhancing herbivore populations' carrying capacities. As a result, invading plants with longer phenology may sustain higher herbivore populations than deciduous native fodder, which might have a detrimental influence on native species due to apparent competition (Smith & Hall, 2016). ELP can exacerbate the impact of invasive species by altering the dynamics of herbivore populations, resulting in cascade impacts on native plant communities. This process can arise as a result of apparent competition, when a plant species impedes another by supporting a common predator. In circumstances of obvious competition, an imported species that increases herbivore density can put pressure on indigenous. In principle, larger levels of herbivory can decrease native species more effectively comparing to competition on resources (Holt, 1977). More and more researchs are conducted on the topic every year. For instance, monitoring studies have found that invasive plant species extend their growing season in autumn by four weeks compared to native species (Fridley, 2011). This extended leaf phenology (ELP) may interact with allelopathy, the release of toxins, if exposure to seasonal light influences allelochemical production (Smith et al., 2014). For instance, a study on invasive garlic mustard (*Alliaria petiolata*) found that manipulation of germination phenology, with earlier germination resulting in higher survival and biomass, emphasized the role played by ELP in causing the invasion of garlic mustard. Eight populations of garlic mustard produced allelochemicals, and analysis of those allelochemicals indicated substantial diversity in glucosinolate responses to light availability (Smith et al., 2015). Prolonged autumns in boreal Alaska might be more beneficial to exotic species than native ones (Mulder et al., 2019). Another study investigated if the phenology of leaves and flowers in native and imported forbs and shrubs in the boreal area is affected by early springs, warmer summers, and prolonged autumns. In North America, many invasive understory woody plants leaf out earlier or keep their leaves for a longer period of time than their native counterparts, which is believed to give introduced species a competitive edge over native species since spring and autumn are critical seasons for understory habitats to acquire light and carbon (O'Connell et al., 2020). The study investigated whether these responses provide an advantage to either group, considering latitude and forest structure.

Researchers discovered that the variation in leaf phenology between native and invasive shrubs can surpass 77 days during a growth season using 1,500 observations of 14 species over the course of four years, and invasive species may lose the competitive advantage gained by ELP (O'Connell et al., 2020). The problem can be mitigated by streamlining management by concentrating on the detection and elimination of invasive shrubs while native plants are dormant. Furthermore, even little modifications to the seasonal phenology can have a big effect on forest populations. To this end, a citizen science research initiative was created in collaboration with the USA National Phenology Network to document broad patterns of species-specific ELP, which might have been an impractically big undertaking (Maynard-Bean et al., 2020).

Seed dispersal is the process through which seeds travel from their parents' local surroundings to establish themselves in a location that's closer to or farther from them (Traveset & Rodriguez, 2008). Zoochory is the dispersal of animals and birds. Birds and animals are dispersion agents. The seeds are often light, sticky, and equipped with hooks. Several plants produce fleshy edible fruits that contain seeds that are spread in the feces generated by mammals (Nagendra, 2020). Ungulates were discovered to distribute 44% of all species present in the environment, demonstrating that ungulates may transfer seeds from a seeds from a large percentage of the local species pool (Albert et al., 2015). Seed dispersal by ungulates provides crucial benefits to the different ecosystems by maintaining native plants in wilds and urban areas, promoting forest bio-regeneration, and native vegetation providing a food chain and food web for herbivores and carnivores (Henry & Maria, 2004). On the other hand, it can facilitate non-native plant species. Guiden et al. (2015) studied the significance of white-tailed deer as seed dissemination vectors of exotic plants. White-tailed deer have the potential to be key seed distribution vectors for the invasive plant, *Lonicera. maackii* seeds were found in 31% of pellet groups. However, another study also focused on one non-native species on Parris Island suggesting that deer may not be important in the spread of the Chinese tallow tree, which has an important management concern on this island (Pile et al., 2015). Another study found that the ungulates are one of the main factors of exotic plant dispersal in the forest ecosystem. By evaluating the dispersal of seeds by ungulates (blackbuck, wild boar, spotted deer, and feral horse, and determining the number of woody vegetations' seeds in fecal samples from different animals the results showed that the germination rate was 100% in wild boar and feral horse (Chandru et al., 2020). A similar study in southern Connecticut found that white-tailed deer play an important role in dispersing exotic seeds, which is an indirect way to alter the plant vegetation. According to the study, 326 non-native seeds (32 species) out of 6566 seeds (57 species) were found in the pellets germinated in 32% of the pellets group (Williams & Ward, 2006).

2.4 Methods for studying the impact of ungulates on non-native plants

The literature provides a variety of methods to study the relationship between ungulates and invasive plant species, but we could categorize them into three main groups: 1-experimental methods: when the researchers manipulate an independent variable (treatment) in controlled conditions to measure its impact on dependent variables (outcomes) (Ross & Morrison, 2003). For example Relva et al. (2010) used enclosure/exclosure experiment and their treatment was the absence or presence of ungulate while the dependent variables were some vegetation features such as seedling and sapling density, maximum height of tree species, and understory cover, and they found that deer has a significant impact on inhibiting the growth and reducing the cover of native species. However, the effects on the abundance of seedlings and saplings of both native and exotic tree species were unclear. This study discovered that introduced deer can facilitate exotic plants through their negative impact on natives. A cafeteria style experiment, i.e., a multiple choice experiment based on animals' foraging behavior in their natural habitat, allowing animals to choose from a wide variety of plants is also a potential approach. Based on the results of this type of method, shows how ungulates choose between different species based on their palatability. This was demonstrated by Averill et al. (2016) the independent variable in this study was the (indigenous / introduced) and the dependent variables were the preference of deer measured by the biomass consumed by deer and the feeding behavior where white-tailed deer showed stronger avoidance of invasive introduced plant species than indigenous plant species. avoidance (*Alliaria petiolata, Microstegium vimineum, and Berberis thunbergii*) preferred: (*Celastrus orbiculatus, Ligus trum vulgare, and Lonicera morrowii)*. 2-observational methods: it is a type of methods observing and gathering data on group and individuals without manipulating the environment they live in. The researcher does not assign subjects to the groups but observe them in their natural habitat and collect data of different variables (Hoffmann&Lim, 2007). Katona et al. (2013) used field observational methods to examine the ungulate selectivity in the understory between 2003-2005, in different regions in Hungary. By counting the number of sprouts available and browsing, the data was analyzed using statistical methods. *Robinia pseudoacacia* was preferred with a Jacobs' selectivity index of 0.04 ± 0.77. Similarly (Wright et al., 2019) used the same methods but their findings indicate that deer consume the non-native species *Lonicera mackii* only in times of scarcity rather than as a preferred food item.

Collecting seeds and germinating them is a method that involves collecting pellets from different ungulate species in areas invaded by non-native plant species. The seeds are then extracted from the pellets and germinated in greenhouse conditions to examine the ability of ungulates to disperse exotic plant species (Forsyth & Davis, 2011; Guiden et al., 2015; Williams & Ward, 2006; Williams et al., 2008).

The diet estimation methods can give information about the ungulate feeding behavior and whether they consume non-native and invasive plant species, such methods include microhistological analysis (Marin, et al. ,2020) and rumen analysis (Karl et al., 1998).

3. Materials and methods

3.1 Paper selection

We conducted scientific research using two databases (Web of science and Scopus) in order to find adequate publications on the impact of ungulates on non-native plant species in forests. We used different key words as following (ungulates OR deer) AND (impact OR browse* OR diet) AND (non-native OR invasive OR exotic). The search range was within the title, abstract and the key words. After scanning the abstracts for each paper, we extracted (51studies) from (3083) article because they contained information about the variables that give answers about our research questions. Some of the papers were obtained from the references of the extracted papers. After, we further read the proper papers and coded the data using excel file.

2.3 Data extraction:

From the researches we obtained as a result of the research process, we extracted the following information: place of study, year in which it was published, the place where the study took place, the type of forest in which the study was conducted, and research methods used, in addition to the invasive plants mentioned in each study and the ungulate type. For the analysis of different relationships, we divided the studies into three sections: studies about selective behavior, studies about the impact of non-native plants on ungulate, and studies about the impact of ungulates on non-native species.

Firstly, the selective behavior of ungulates towards woody species: we separated the studies based on the methods used, where we chose only studies that included cafeteria style and selectivity indices, etc. Based on the results of the study (the preferred plant type and the value of the indices, +/-, etc.), we decided if the non-native plant was selected or not by giving the study a yes/no value.

Second, the impact of invasive plants on ungulate: we selected these studies through the title and also the research results. Based on the results, we were able to extract a set of themes. Because of the complexity of this kind of relationship, we got seven themes that summarize the pattern of the relationship between the ungulate and the non-native. To find out whether the relationship is positive or negative, we based it on the results of the research. The relationship was negative when the invasive plants caused a significant decline in the habitat, abundance, feeding behavior, and food quality of the ungulate. The relationship was positive when the invader plants caused an improvement in the food, reproduction, abundance, behavior, etc.

Third, the ungulate effect on invader plants: we have separated these studies by title and search results. In this type of study, we extracted results and variables. Through it, we deduced the different relationships according to the type of influence and divided it into: 1) positive (indirect facilitation) when the animal creates a suitable environment for the non-native plants through seed dispersal, suppression of natives, habitat release, trampling, etc., or 2) negative (direct hindrance) when the animal consumes non-native plants by grazing or browsing, 3) species-specific: this type of study contains more than one type of negative, positive, or no effect relationships, depending on the type of non-native plants mentioned in the study. For this purpose, we created a separate table with the effect of the animal on each plant separately. 4) No impact: when the results show that there is no significant relationship between non-native plant variables and animal impact.

In the end, we visualized the different data in the form of figures to be included in the review.

4. Results

4.1 General findings

We extracted 51 publications that met our criteria and investigated the relationships between ungulates on non-native plant species in forest ecosystems. Most of the studies were conducted in the United States, with 34 publications (67% of total). Argentina was the second most frequently studied country, with 7 publications (13%), followed by India, Hungary and Australia (n=2, 4%). While Nepal, Malaysia, Sri Lanka, and Uganda each represented 2% of the total studies with one study each. (Figure 1) provides a map of the countries represented in our review, along with the number of publications.

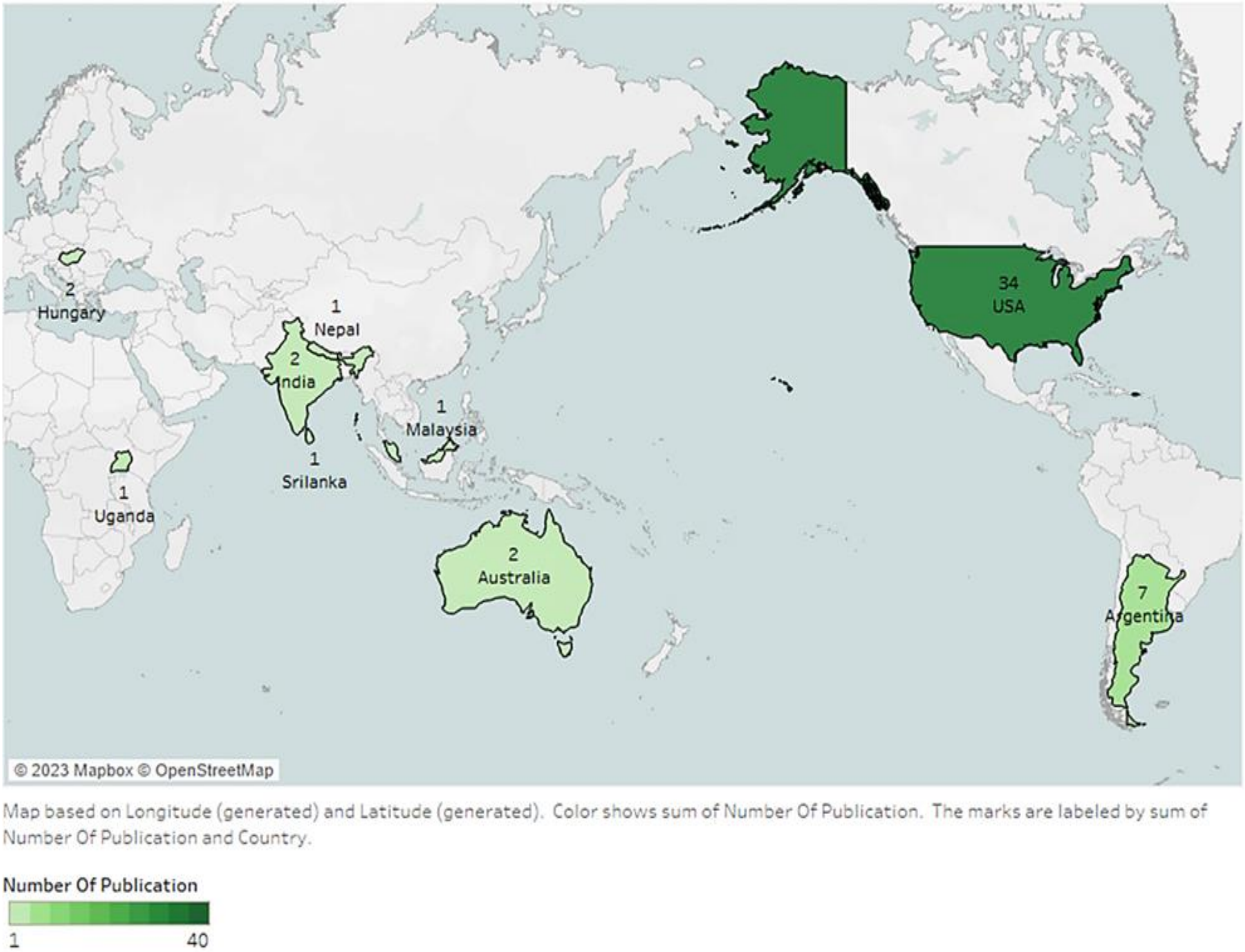

Figure 1: The map expresses the geographical distribution of studies that illustrate the different relationships between ungulates and non-native plants based on numbers and different color intensity, we note the distribution of studies on all continents with the largest percentage in North America.

The publications date was between 1995 and 2022, with the majority (n = 34) being published in the United States. The most recent study in our data set was conducted in Nepal in 2022. While the oldest one was published in America in 1995. Figure 2 shows the distribution of the publications over the years. We can observe that the majority of the studies were published during the past decade with 29 (55%) between 2012-2022. The USA has the largest number of publications with at least one publication each year except 2010 and 2022.

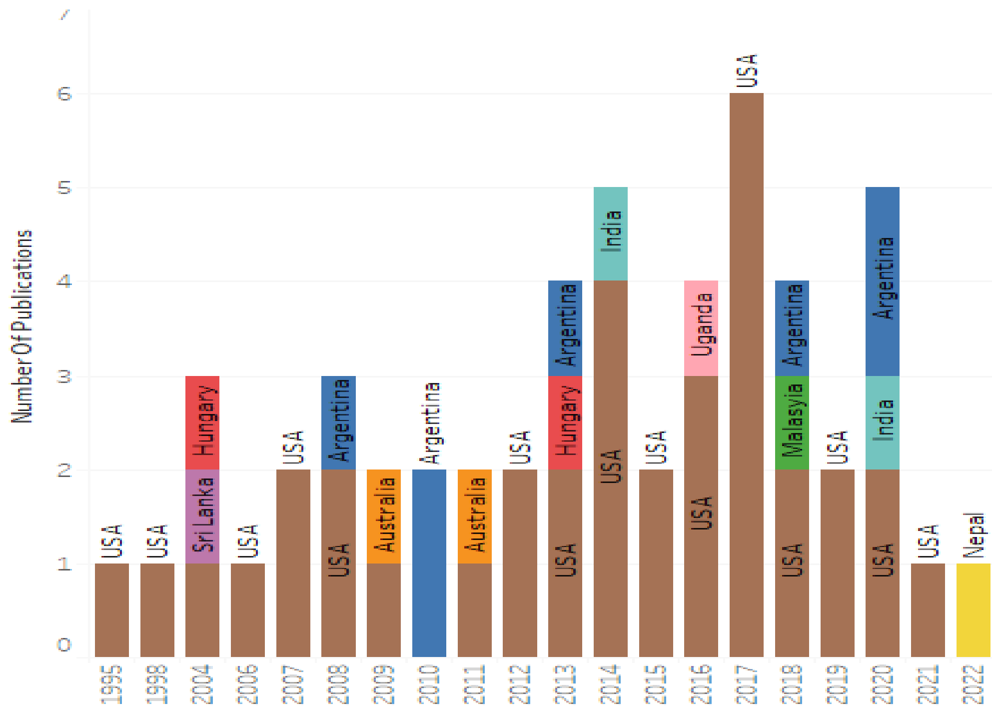

Figure 1 The figure shows the distribution of studies over the years starting from 1995 to 2022, in addition to the number of studies published in each country during the different years.

The fact that a large number of papers were published in the last ten years demonstrates researchers' increased interest in the topic.

4.2 Ungulates selectivity towards non-native woody plant species

We found through our research that only five studies matched the research criteria for ungulates selective behavior. Three of these studies (from Hungary and two from the United States) found that ungulates had a preferential selective behavior towards woody invasive plants. While two studies (from Argentina and United state) found that there was no evidence for such preferential behavior. (Figure 3) Non-native plants differed from one study to another as well as the research methods used to test this behavior, three studies used a cafeteria experiment and two studies used selectivity behaviors (Annex 3).

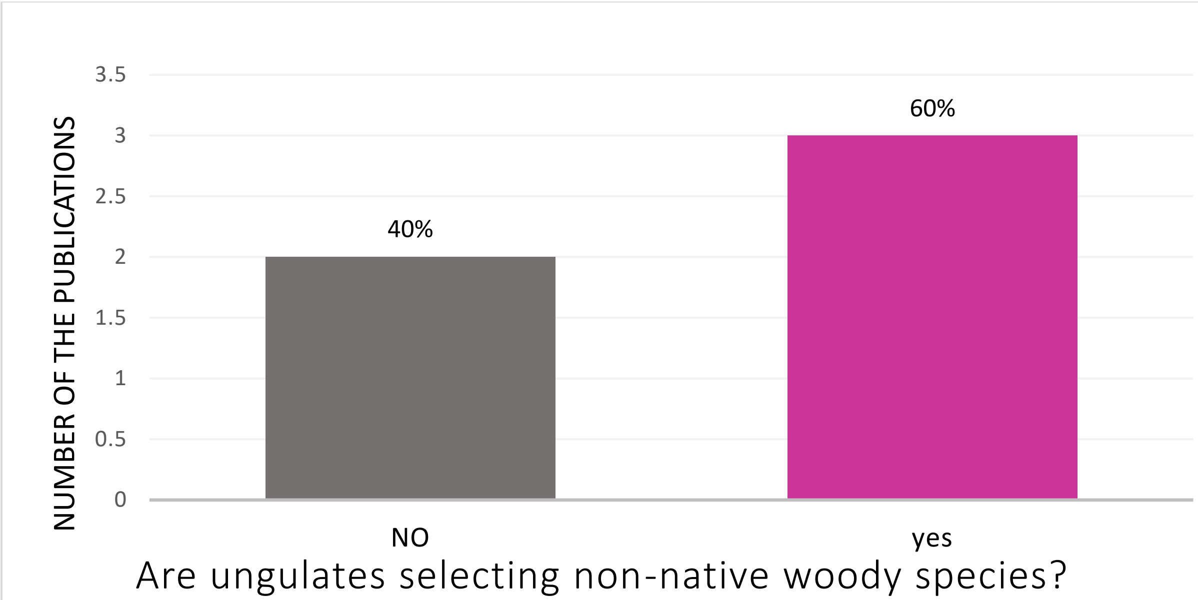

Figure 3 The figure shows the selective behavior of ungulates towards non-native plants, which appears in 60% of cases.

4.3 Non-native plants impact on the ungulates

Of the ten studies related to the effect of invasive plants on ungulates, 4 studies (40%) showed a negative impact of invasive plants and six studies (60%) of the total studies showed a positive impact of non-native plants on ungulates (Figure 4).

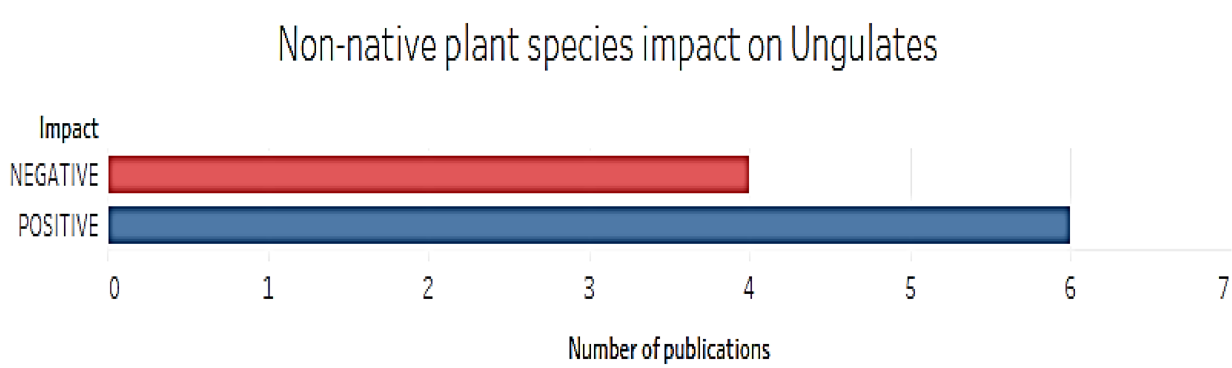

Figure 4 The figure shows the effect of non-native plants on ungulates (number of publications with positive or negative results). The positive effect is prevalent in most cases.

4.4 Ungulate impact on the non-native plants

Our results showed that the impact of ungulates on invasive plants was generally positive (23 of the studies), although the negative impact was present in 11 studies. In addition, some of the studies we collected were species-specific (9 studies).In this case the studies looked at the impact of the ungulate on specific none-native plant species for example (honey suckle), resulting in different results (negative, positive, no impact) appendix (3). That means instead of investigating the relation between the ungulates and the non-native plants in general or (at the community level). These studies focused on the relationship between the ungulate and a specific plant species at the individual level. Here we can see that the results varied between (negative – positive- no impact) reflecting how the ungulate can impact each plant in the ecosystem separately depending on some factors (palatability, food scarcity…etc.) While only one study showed that there is no impact of ungulates on invasive plants, as the results of the study showed no significant effect of ungulates on non-native plant species (Figure 5).

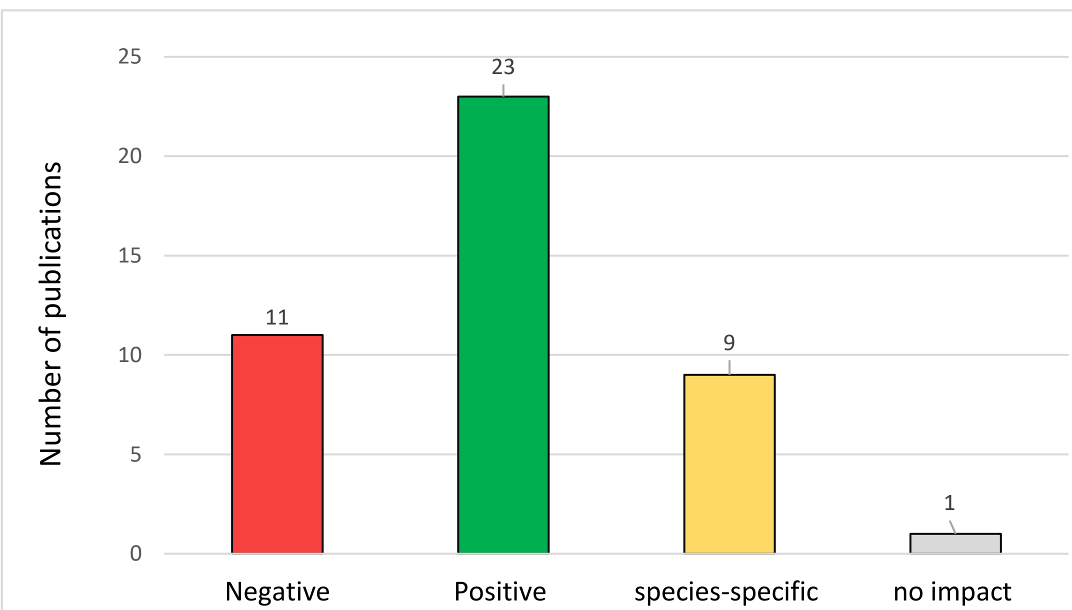

Figure 5: The figure shows the effect of ungulates on non-native plants.

We did further analyses to the results and divided the positive type of impact to1-suppression of natives: This includes studies which results showed the preference of ungulates for native plants as food and thus the liberation of invasive plants from competition with natives. According to our results This type of effect was prevalent in the studies we collected by 23%. 2- Seed dispersal type of impact: Here the ungulate plays the role of an agent to transport the seeds of the non-native plants and help in their germination and spread to new areas. This type of positive effect was second in terms of the number of studies we collected (n=9). 3-Resources release: In this type of effect, the animal creates the appropriate environment for the spread of non-native plants by creating gaps in the ecosystem, providing light, improving soil and other processes that are suitable for the spread of invasive plants. This type of studies was the third in terms of importance, as the number of publications we collected was (n=3). 4- The last type was Trampling: where animals contributed to the spread of non-native plants through the Trampling process in the soil, the number of studies that proved this type of effect was (n=2). In addition, there are two studies in which the nature of the positive effect of ungulates on non-native plants was not mentioned (Figure 6).

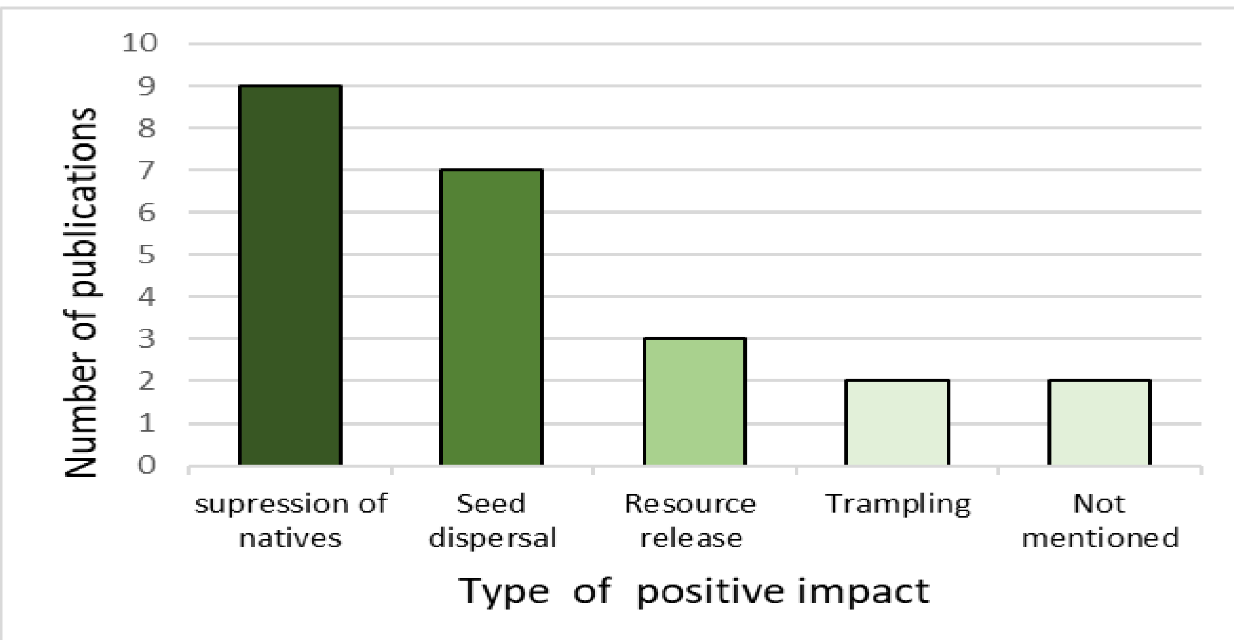

Figure 6:The figure shows the different types of indirect positive effect of ungulates. It includes the different types of effects extracted from different studies that dealt with the positive effect.

The negative or direct hindrance from ungulates on invasive plants also happens. This type of effect occurs only when the ungulate grazes or browses non-native plants, limiting their spread in the forest ecosystems. The third type of impact mentioned in the (Figure 7) is the species-specific impact. 9 publications reported this kind of impact, indicating that the impact of ungulates on non-native plant species can vary depending on the plant species characteristics and the ungulate species. In our case, white-tailed deer was the main ungulate that had different types of impact at the individual plant species level (n=9) (see Figure 5). The various studies showed how ungulates affected different plant parameters such as abundance, density, and other growth parameters. The impacts were either positive when the ungulates increased the measured variables or negative when these variables decreased in the presence of ungulates. In some cases, ungulates had no impact. All of these impacts differed according to the plant species present in the study (see Annex 4).

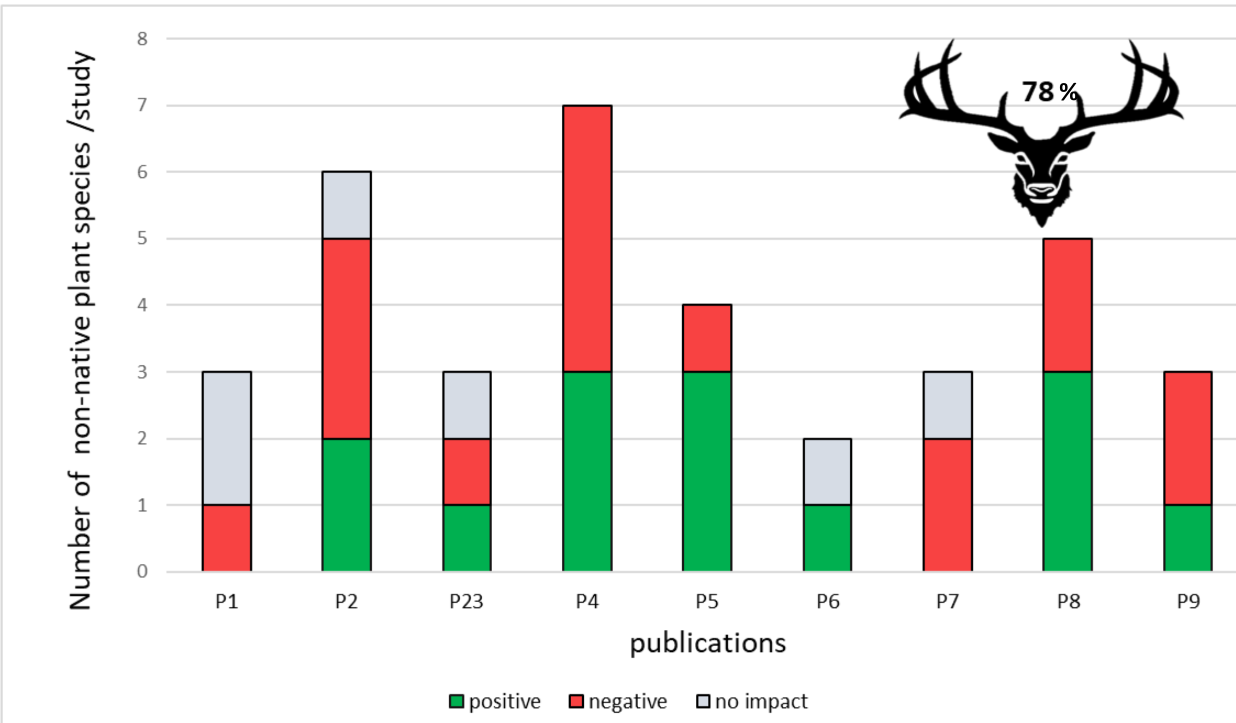

Figure 7: The figure shows the species-specific impacts of ungulates on invasive plant species- in a single study considering 9 different publications.

5. Discussion

The results obtained from our research on the selective feeding behavior of ungulates over non-native plants in the forest ecosystems show the complexity of this topic and the importance of taking into account the different research methods and different plants between studies. Our review showed that only five studies met the search criteria, three of which showed evidence of preference and two of which showed no evidence towards exotic plants. Other researchers that studied the selective feeding behavior of ungulates found that the effect of herbivores on plants in the ecosystem is a complex relationship that cannot be limited to herbivory – plant dimension, but includes other factors (Nopp-Mayr et al., 2023) such as: palatability of plant species (Augustine & McNaughton 1998; Roony & Waller, 2003), ungulate density (Putman & Moore, 1998; Ramirez et al. 2018), forest management practices (Kuijper et al.2009 ; Kramer et al., 2006), plant characteristics (Fehér & Katona, 2016). In general, forest and wildlife management should take into account the effects of ungulates on different plants, in addition to the environmental and biological factors that can affect this interaction.

The effect of non-native plants on ungulates can be both positive or negative. In our review we found that these effects can be divided into groups:

1- The negative effect of invasive plants on the ungulate populations, and habitat use: the abundance of deer and wild pigs decreased when the abundance of invasive *Mikania micrantha, Chromolaena odorata, Lantana camara, and Parthenium hysterophorus* increased with a correspondent decline in habitat use of elk, bison and deer in the infested areas by *Euphorbia esula, Bromus inermis, Bromus japonicus* and *Bromus tectorum) (*see Annex2*).* These results suggest that the invasive species negatively impact the ecosystem function and the habitat. That make our study in accordance with the previous researches which indicated the negative impact of the non-native plant species on the different types of ecosystems and their components. For example, Gerber (2008) found that *Fallopia* plant can negatively impact the riparian ecosystem. The plant can reduce the quality of the ecosystem as a habitat for the amphibians, reptiles, birds and mammals. Similarly, Schirmel et al. (2016) found that the invaders *Prescence* reduced the fitness of plants by 52% and the animal variety by 33% and the animal abundance by 29%.

2- Impact of non-native species on feeding rate: we also observed that invasive plants can cause food scarcity by reducing the feeding rate of the animals. Elephants feeding rate was reduced in the areas invaded by invasive *Lantana camara* (Annex 2). This consideration is important to understand the potential impacts of invasive species on the animal health, fitness and population dynamics. This impact could be negative as stated by the meta-analysis in Cameron et al. (2018), who found that invasive plant species reduced the overall abundance, variety, fitness and feeding types for different animals in different habitat types. Or positive where Utz et al. (2020) found that Intensive foraging by small mammals may be increased by exotic plants.

3-Positive impact of non- native plants on habitat and reproduction: our findings suggest that non-native species could provide benefits to the ungulates. Specifically, we found that non-native forest species can provide good quality food and shelter for the red deer and the ungulates could shift their diet to include non-native species only in times where the natives are scarce like early spring (e.g., honey suckle) and fall and winter (e.g., privet). Additionally, there was a correlation between birth rate and exotic plant fruit fall suggesting an impact on the ungulates reproductivity (Annex 2). From this finding we could conclude that non-native species support apparent competition (Smith & Hall, 2016) and ELP (Holt, 1977) theory to roll over natives.

We found that ungulates can have different types of impacts on non-native plant species, including positive(n=23),negative(n=11), species specific (n=9) and no impact(1) .Depending on the results we obtained, the positive impact of the ungulates (facilitation) consists of a set of effects that vary according to the type of animal, the role it plays in the ecosystem and the nature of the non-native plants: 1- suppression of native species: indirect facilitation occurs when ungulates help in the spread and proliferation of non-native plant species , indirectly aiding in their competition with native species. Most of the positive results were of this type; for example, in Argentina, Fallow deer and Red deer significantly reduced the abundance and cover of native tree saplings, while having a smaller effect on the abundance and cover of exotic tree saplings (*Pesudetsuga menziesii*). Another study conducted a cafeteria experiment and found that ungulates (*Cervus elaphus, Dama dama and Axis axis*) preferred browsing on the native tree species over the exotic conifers, resulting in facilitation to the exotic plant (*Pseudotsuga menziesii a*nd *Pinus ponderosa*) in the forest ecosystem. Similarly an experimental study conducted in Uganda, found that non-native tree species (*Eucalyptus grandis and Grevillea robusta*) showed higher survival rate when exposed to large ungulates and termites compared to indigenous plant species. This suggests an indirect facilitation, where large ungulates and termites indirectly reduced the competition between native plants and non-natives (Annex1).

2- Seed dispersal: our review showed that ungulates can play a significant role in dispersing non-native plant species and introducing them to new ecosystems. Guiden et al. (2015) found that white-tailed deer were potential seed distribution vectors for *Amur honeysuckle*, while Chandru et al. (2020) evaluated the dispersal of seeds by various ungulates and found that they were one of the main factors in the exotic plant dispersal in forest ecosystems. Williams and Ward (2006) examined the potential of white-tailed deer in dispersing exotic plant species in southern Connecticut and found that they played an important role in altering plant vegetation.

3-Resource release : This type of impact is also indirect facilitation. Ungulates create a favorable environment for invasive species by changing some of the habitat's properties. For example an exclosure experiment conducted in USA found that *Microstegium vimineum* was 3.3 times lower in areas that were not browsed by deer compared to areas that were browsed.The deer indirectly facilitate the non- native species through creating gaps and providing light required for the exotic plant. the same facilitation was found in the other two studies were ungulates facilitate the non-native by providing suitable habitat features (Annex 1).

4-Trampling: Indirect facilitation, where feral pigs facilitate *Psidium cattleianum* and S. *palmifolia* non-native plants, and Elk trampling facilitates North Africa grass (*Ventenata dubia*), through soil disturbance. This disturbance increased the abundance of the none-native species in the disturbed areas (Annex1).

The negative impact (hindrance) caused by the ungulates was limited to their consumption of the plants'; Bornean banteng browsing eight invasive species, which was identified by diet estimation using camera trap photographs. or sheep grazing preferentially the none-native *Pinus contrata* which was indicated by two enclosure studies. (Annex 1). The hindrance of non-native species by ungulates proves that ungulates as a part of the ecosystem have the ability to keep the invasion process in check and limit their spread. These results give support to the biotic resistance hypothesis (Levine et al, 2004).

Our results indicated that the impact of ungulates can be of different types, negative, positive, no impact, within the same ecosystem. This situation arises when the relationship between the ungulates and the non- native plant species is studied on the individual level instead of the community level. This type of impact is observed in studies that focus on the effect of ungulates on specific plant species. For example; (Averill et al. 2018) found that while white -tailed deer reduced the abundance and the growth of *Lonicera japonica, Lonicera maackii and Rosa multiflora*, the deer increased the growth and abundance of *A. petiolata and M. vimineum* and has no impact on *A. altissima*. Similarly, (Erickson et al., 2017) found that white-tailed deer browsed the exotics: *Lonicera sp, Elaeagnus sp and Rubus phoenicolasius* and avoided *Alliaria petiolata.* (Annex 4).

6.Conclusion and Recommendation

The research on the impact of ungulates towards non-native invasive species in forest ecosystems, had shed light on the diverse relationship between them. Ungulates selected woody non-native species in 60% of the cases and avoided them in 40%. This selectivity may play an important role in forest management and habitat conservation decision making. For instance, introducing none- native commercial woody species less preferred by the ungulates can reduce the conflict between forest and wildlife managers by reducing the damage caused by ungulates. On the other hand, non-native woody species when selected by ungulates can mitigate the pressure on native species allowing them to survive harsh environmental conditions. As an ecological relation between plants and animals the selectivity can be complex impacted by many types of factors (abiotic, biotics). The impact of non-native plant species varies between negative and positive types. The negative impact on habitat use, ungulates abundance and feeding rate were indicated. On the other hand, non-native species could provide benefits to the ungulates by dietary shift, reproduction enhancement and population increase. This requires monitoring to the wild ungulates and the non-native plants population in order not to reduce the ecosystem biodiversity. Moreover, the positive impact from ungulates to exotics can be manifested by suppression of native plants, seed dispersal, resource release, and trampling. in this case ungulates culling or control practices may be required to limit the spread of the non-native plants While the negative impact was limited to browsing/grazing. results on species -specific ungulate impact type suggest that deer can have a mixed impact on invasive species in forest ecosystems. For example, culling or regulating the deer population alone may not be enough to effectively manage non-native species in the ecosystem. Management efforts will also need to include controlling the non-native plant species that may increase in abundance after deer control, outcompeting native species. Further research should be conducted to understand the complex relationship between ungulates and non-native species, considering other factors that may intervene in this interaction. When entering a new environment, non-native species will face countless possibilities, from the characteristics of the plant itself to the types of enemies that exist, as well as the resilience and naturalness of the ecosystem. All of this together will determine the type of relation between the animal and the plant.

Based on the review our Recommendations can include:

i. Reduce deer population to minimize the pressure on native species and reduce the negative impact of the deer in the ecosystem.
ii. Control or eradicate non-native plant species to reduce competition with native plant species.
iii. Consider the combined effect of different stressors, such as drought, invasive species, and herbivory, on the ecosystem, and take early action to mitigate their impact.
iv. Implement biodiversity conservation by promoting multi-species understory and preserving a range of native plant and animal species in the ecosystem.
v. Recognize that different ungulate species can have varying impacts on invasive species. Therefore, management efforts need to consider the specific non-native plant species present in the ecosystem.
vi. Use the combination of invasive species management and deer population reduction to manage non-native species in the environment. This will entail suppressing non-native plant species that might displace native plants following deer management, as well as eradicating or managing deer populations.
vii. Conduct regular monitoring for the ungulates and non-native plant species, to assess the efficiency of the management process.

7.Summary

Large herbivores have a significant impact on plant communities, in both positive and negative way. While some studies support the biotic resistance hypothesis (BRH) that natural generalist herbivores minimize plant invasion by consuming non-native species, other studies suggest that herbivores have a more facilitative effect on exotic plant abundance. The controversy surrounding the topic has led to a growing interest in understanding the interactions between ungulates and non-native plant species in forest ecosystems. A systematic literature review was conducted to answer these questions: 1) Are ungulates selecting non-native woody

species? 2) Do the non-native plants have any kind of effect on ungulates? 3) What is the impact of the ungulates on non-native species in forest ecosystem?

we conducted a scientific review using two databases to find studies on the impact of ungulates on non-native plant species in forests. We extracted data from 51 studies and coded it using an excel file. The studies were divided into three sections: selective behavior of ungulates towards woody species, impact of invasive plants on ungulate, and ungulate effect on invader plants. Then we extracted information such as place of study, year of publication, forest type, invasive plants mentioned, and ungulate type to analyze the different types of relationships.

This study extracted 51 publications. The majority of the studies were conducted in the United States (67%), with (n = 34) being published in the United States. The review observed that ungulates exhibited preferential selective behavior towards woody invasive plants, while two studies, did not find evidence for such behavior. Non-native plants impact on the ungulates 40% of the ten showed a negative impact of invasive plants, while 60% showed a positive impact. Our research found that the impact of non-native plants on ungulates was generally positive, with 60% positive impact and 40% negative impact. The positive impact (n=23) varied, with 23% of studies showing the suppression of native plants and 9 studies showing positive impacts through seed dispersal. Ungulates also had negative impacts on invasive plants, with 11 studies reporting this type of effect. And some studies focused on the relationship between a specific plant species and ungulates at the individual level resulting in species-specific type of impact.

The impact of ungulates on non-native plant species can be positive, negative, species-specific, or have no impact at all, depending on the type of animal, its role in the ecosystem, and the nature of the non-native plants. Ungulates can facilitate non-native plant species through indirect facilitation, seed dispersal, resource release, and trampling, while hindering their spread through consumption.

The relationship between ungulates and non-native invasive plant species in forest ecosystems is complex and varied, with both positive and negative impacts on each other and the ecosystem. To effectively manage non-native species in the environment, it is necessary to consider the specific non-native plant species present and implement a combination of invasive species management and deer population reduction. To effectively manage ecosystems, it is important to reduce deer populations, control or eradicate non-native plant species, consider the combined effect of different stressors, promote biodiversity conservation, recognize varying impacts of ungulate species on invasive species, use a combination of invasive species management and deer population reduction, and conduct regular monitoring

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10. Appendices

Annex (1) shows the data related to the ungulates impact on non-native plant species

Impact	POSITIVE	POSITIVE	POSITIVE	POSITIVE
TYPE OF IMPACT	indirect facilitation through seed dispersal	indirect facilitation (deer select on palatable native species)	indirect facilitation (trampling)	indirect facilitation through seed dispersal
Results		deer avoided p.arundinacea (the invasive cover increased in deer Prescence)	increase the densities of nonnative plants through soil disturbance.	
VARIABLES		Winter browse intensity. - Vegetation composition: including both native and invasive species. - Reed canary	Density of native woody plants rooted in mineral soil - Establishment of native woody plants as epiphytes - Stem density of young tree ferns - Herbaceous cover - Number of species - Density of the nonnative invasive shrub, Psidium cattleianum	
METHODS	pellet collection/seed germination	field survey; samples within plots: then the data computed to test the relation between different variables.	fenced (pig-free) vs. unfenced (pig-present)	fecal pellets collection and germination
NON-NATIVE PLANTS	exotic woody weed tree Prosopis juliflora	Phalaris arundinacea	Psidium cattleianum (shrub), S. palmifolia (herbaceous)	in general,
UNGULATE SPECIES	blackbuck, spotted deer, wild boar and feral horse	Odocoileus virginianus	nonnative feral pigs	hog deer
HABITAT	protected forest area	restoration sites of floodplain forests	wet forested area	Wilsons Promontory National Park (forest)
COUNTRY	India	USA	Hawaiian Islands	Australia
AUTHOR	Chandru et al. 2020	Cogger et al. 2014	Cole et al. 2012	Davis et al., 2010

Impact	POSITIVE	POSITIVE
TYPE OF IMPACT	indirect facilitation (native plants are being heavily browsed by deer while the Japanese stiltgrass is being avoided.)	indirect facilitation by trampling, **Elk** winter movement can cause soil disruption and invasive plant development. establishment.
Results	the growth and spread of Japanese stilt grass, which was more prevalent in areas where deer were present	North Africa grass (Ventenata dubia) increased in winter due to elk traffic.
VARIABLES	vegetation cover variables such as plant species richness, percentage of forbs, shrubby vegetation, taller stems, grass, and exotics. In addition, invertebrates were counted and measured by order, and biomass was measured for each sample.	elk herd counts, pellet group counts, and soil displacement, and compared vegetation and soil-related variables between the two categories using statistical tests.
METHODS	experimental approach by constructing deer exclosures	established plots in plant associations that were potentially impacted by elk to monitor changes in vegetation over time.
NON-NATIVE PLANTS	Japanese stilt grass	North Africa grass (Ventenata dubia)
UNGULATE SPECIES	white-tailed deer (Odocoileus virginianus Zimmerman)	elk
HABITAT	Middle Patuxent Environmental Area (MPEA). suburban environment with a mix of forest, meadow, and wetland habitats	forest and shrub land
COUNTRY	USA	USA
AUTHOR	Duguay and Farfaras 2011	Johnson et al., 2013

Impact	POSITIVE	POSITIVE
TYPE OF IMPACT	indirect facilitation (by reducing the abundance of native plants)	indirect facilitation (dee are releasing available resources such as open space and light, by decreasing woody plant cover and abundance)
Results	increasing deer density led to increase in exotic species density	Microstegium vimineum was 3.3 times lower in areas that were not browsed by deer compared to areas that were browsed.
VARIABLES	the densities of large seedlings, saplings, and trees, as well as changes in the cover of native and exotic herbs and shrubs. The study also measured changes in tree species composition in relation to deer browse preferences.	abundance of Microstegium vimineum, plant diversity, woody plant cover, and several abiotic factors such as soil moisture, total soil carbon and nitrogen, and soil ph.
METHODS	data from 62 stands were collected between 2014-2018 were compared with historical data collected in the same sites when deer population was less between 1948–1973	exclosure Experiment
NON-NATIVE PLANTS	not mentioned in species but general classification (shrubs, herbs, lianas)	Microstegium vimineum.
UNGULATE SPECIES	white-tailed deer (Odocoileus virginianus)	white-tailed deer (Odocoileus virginianus Zimm.)
HABITAT	The region's forests are mostly made up of oak-hickory, mixed hardwoods, and northern hardwood species.	early-successional forest and agricultural patches.
COUNTRY	USA	USA
AUTHOR	Kelly, 2019	Kuebbing et al. 2013

Impact	POSITIVE	POSITIVE	POSITIVE
TYPE OF IMPACT	indirect facilitation through suppressing natives	indirect facilitation (seed dispersal)	indirect facilitation (preferential browsing of native herbs and act as an important seed dispersal agent for exotic)
Results	pigs can reduce the abundance of native plant species, which can create opportunities for invasive nonindigenous plants to establish and thrive.		abundance of introduced plant species increased in areas with higher deer density.
VARIABLES	plant species richness, plant cover, litter depth, soil compaction, and soil moisture. These variables were measured both inside and outside of exclosures to compare the effects of feral pigs on vegetation.		forest structure, tree seedling abundance, and the presence/abundance of introduced plant species across varying deer densities and forest types.
METHODS	exclosure studies to assess vegetation change caused by feral pigs	pellet collecting, seed planting	forest analysis: using permanent sample plots (FIA) program, 2-deer density 3-deer impact on tree seedlings.
NON-NATIVE PLANTS	non-native species	Chinese tallow tree, and herbaceous and woody plants	not mentioned in species but general classification (shrubs, herbs, lianas)
UNGULATE SPECIES	feral pigs	white tailed deer	white-tailed deer (Odocoileus virginianus)
HABITAT		mixed maritime pine forest on Parris Island	large scale forest in the north = mainly broad leaves forests.
COUNTRY	USA	USA	USA
AUTHOR	Nogueira-Filho et al., 2009	Pile et al., 2015	Russell et al., 2017

Impact	POSITIVE	POSITIVE	POSITIVE
TYPE OF IMPACT	indirect facilitation	indirect facilitation (long distance seeds dispersal)	indirect facilitation through seed dispersal
Results	cover of this invasive species initially increased after deer culling began, but then decreased. They **further** discovered that plots with greater M. vimineum cover had higher seedling numbers.		
VARIABLES	density of tree seedlings and the cover of an invasive grass species called Microstegium vimineum , growth of tree seedlings over time		
METHODS	field survey In 49 plots between 2006 and 2017, the researchers recorded the presence of trees, bushes, saplings, and stilt grass; deer	pellet collecting and germination	collecting pallet groups, then planting the vernalized seeds in green house conditions to estimate the
NON-NATIVE PLANTS	Microstegium vimineum	More than 70 different types of germinating seeds (including plants, shrubs, and trees) sprouted from the pellets.	non-native species
UNGULATE SPECIES	white tailed deer	white-tailed deer (Odocoileus virginianus)	Odocoileus virginianus 9white tailed deer)
HABITAT	deciduous forest	farm fields, an ancient field, a roadside, and a residence's lawn all surround a woodland.	forest managed for timber harvesting
COUNTRY	USA	USA	USA
AUTHOR	Schmit et al. 2020	Vellend et al., 2004	Williams and Ward 2006

Impact	POSITIVE	POSITIVE
TYPE OF IMPACT	INDIRECT facilitation, by creating open areas and reducing competition from native vegetation	indirect facilitation
Results	invasive grass species Microstegium vimineum was present in high cover in the understory of the Liriodendron tulipifera forest stand, which had been intensively browsed by deer.	The abundance of all three invasive plant species increased significantly more in the control plots (where deer were present) than in the paired exclosures (where deer were excluded).
VARIABLES	Deer population density - Overstory and understory vegetation data in three different forest stands - Sapling and seedling densities of various tree species - Shrub cover - Plant species diversity and richness	White-tailed deer population density, the profusion of three invasive plant species (Microstegium vimineum, Alliaria petiolata, and Berberis thunbergii), and the degree of canopy disruption driven by an exotic insect pest,
METHODS	fenced and unfenced paired plots established in 1992	experimental method, specifically repeated censuses of exclosures and paired controls, to investigate the role of white-tailed deer in the invasion of exotic plant species.
NON-NATIVE PLANTS	Microstegium vimineum (Japanese stiltgrass)	Microstegium vimineum, Alliaria petiolata, and Berberis thunbergii
UNGULATE SPECIES	white-tailed deer (Odocoileus virginianus Zimmerman)	white tailed deer
HABITAT	three forest stands, two of which were dry Quercus spp. forests and one of which was a mesic Liriodendron tulipifera	eastern hemlock (Tsuga canadensis) forests
COUNTRY	USA	USA
AUTHOR	Abrams and Sarah 2012	Eschtruth and Battles, 2009

Impact	POSITIVE	POSITIVE	POSITIVE	POSITIVE
TYPE OF IMPACT	indirect facilitation (browsing increased light availability and soil disturbance, AND reduced the abundance of native plant species)	indirect facilitation (seed dispersal)	indirect facilitation (effected the growth of exotic less than natives (facilitation) the invasive has higher	indirect facilitation to exotic by preferring native
Results	all the factors specially deer and worms increased the overall abundance and presence of the non-natives they were present in 46% of the plots		non-natives showed higher survival rates when exposed to large herbivores and termites compared to the indigenous species,	preferred browsing on the native tree species over the exotic conifers.
VARIABLES	deer browse damage (percentage of woody stems browsed by deer in each plot), the abundance of non-native plants, and the presence of earthworms.		the survival probabilities and logarithmic growth of seedlings	the number of individuals attacked and the degree of browsing on each tree species.
METHODS	observational approach and a structural equation modeling (SEM)	2-browse preference experiment: comparison between browsing on the stem or fruits of the plant. 2-	2m heigh fence/ open plot with planted trees saplings	cafeteria experiment
NON-NATIVE PLANTS	most abundant species were Berberis thunbergii, Frangula alnus, and Lonicera spp.,	lonicera maackii	Eucalyptus grandis and Grevillea robusta a	Pseudotsuga menziesii and Pinus ponderosa (trees)
UNGULATE SPECIES	UNGULATE SPECIES	white tailed deer	impala and bushbuck Zebra, Tragelaphus scriptus Waterbuck Equus burchelli African	Cervus elaphus [elk or red deer], Dama dama [fallow deer] and Axis axis [axis deer]
HABITAT	7 national parks, forest protected areas, mixed forests of spruce fir, -white pine-hemlock	Row crops, patches of forests, old fields	thickets, open savanna, woodland,	primary or substantial secondary forest dominated by Nothofagus
COUNTRY	USA	USA	Uganda	Argentina
AUTHOR	Fisichelli and Miller ,2018	Guiden et al. 2015	Moe et al 2016	Nuñez et al. 2008

Impact	POSITIVE	POSITIVE	POSITIVE
TYPE OF IMPACT	indirect facilitation (suppression of native plant species)	indirect facilitation (browsing - mediated invasion)	indirect facilitation through seed dispersal
Results	The number of non-native plants, its quantity, growth, and population growth rates all decreased after deer were eradicated.	deer browsing significantly reduced the abundance and cover of native tree saplings, while having a smaller effect on the abundance and cover of exotic tree saplings	
VARIABLES	species presence and cover, growth, reproduction, height, and community composition.	Seedling density, Sapling density and size (native and introduced). Understory cover	
METHODS	culling. 12 forests. Zone1: deer population were reduced by culling 90%in 1998, took place from 1992-2006 zone 2: fenced/ open. interactive of deer invasive and worms from2009-2012. Within 1 m2 quadrate	exclousure /control (4 years study)	pellet collecting/seed vernalization/ germination in green house conditions
NON-NATIVE PLANTS	Alliaria petiolate, Berberis thunbergii, Microstegium vimineum	pesudetsuga menziesii (tree)	invasive species
UNGULATE SPECIES	white tailed deer	invasive ungulates (red deer and fallow deer)	white-tailed deer (Odocoileus virginianus)
HABITAT		native forest: (southern beech (Nothofagus dombeyi) or Austrocedrus chilensis (hereafter Austr ocedrus) or mixed forest with N. dombeyi-	forest managed for timber harvesting
COUNTRY	USA	Argentina	USA
AUTHOR	Nuzzo et al. 2017	Relva et al. 2010	Williams et al. 2008

Impact	NEGATIVE	NEGATIVE
TYPE OF IMPACT	direct hindrance (browsing)	direct hindrance (browsing)
Results	there is 9 non-native species out of 105 in the diet,	the diet of Bornean banteng consisted of eight invasive plant species, (the plants were facilitated by logging)
VARIABLES		site characteristics such as open degraded areas with lower plant species richness and higher elevations. The paper also identified the plant species that make up the banteng's diet
METHODS	estimated diet of 102 samber stomach using macroscopic and microhistological technique	camera trap to estimate the ungulate population, botanical survey, canopy extent: open: leaf cover less than 50% closed: more than 50%, diet estimation (camera trap photographs)
NON-NATIVE PLANTS	European black nightshade (Solanum nigrum), and noxious weed spear thistle (Cirsium vulgare) black berry	A total of eight invasive species (Desmodium triflorum, Eleusine indica, Chromolaena odorata, Cyperus difformis, Mikania cordata, and Chromolaena odorata) have been identified.
UNGULATE SPECIES	samber(non-native)	Bornean banteng
HABITAT	mixed Eucalyptus dominated forest	Maliau Basin Conservation Area (MBCA), Sipitang Forest Reserve (SPT), Tabin Wildlife Reserve (TWR), Malua Forest Reserve (MFR), and Sapulut Forest Reserve (SPL)).
COUNTRY	Australia	Malaysia
AUTHOR	Forsyth and Davis 2011	Gardner et al. 2019

Impact	NEGATIVE
TYPE OF IMPACT	direct hindrance (browsing)
Results	1- deer prefer the non-native Robinia pseudoacacia over native species like Quercus spp. and Fagus sylvatica2- the study used Jacobs' selectivity index with positive values related to the non-native species
VARIABLES	
METHODS	Field surevy:species composition availability of browsing/unbrowsing impact, Jacobs' selectivity index from 2003-2005
NON-NATIVE PLANTS	robinia pseduacacia
UNGULATE SPECIES	Red deer
HABITAT	5 even aged forests
COUNTRY	Hungary
AUTHOR	Katona et al. 2013

Impact	NEGATIVE	NEGATIVE
TYPE OF IMPACT	direct hindrance	direct hindrance (browsing)
Results	The study found that after the removal of ungulates, vegetation cover increased significantly, with most of the change attributable to exotic plant species.	38% of the marsh deer's yearly diet consisted of plant species.(Salix sp. and Populus R22) had low seasonal representation (5.5%).
VARIABLES	plant growth and performance, including vegetation cover, canopy height, fractional cover, and population growth rate. The study also uses remote sensing technology to analyze satellite observations of vegetation phenology and assess changes in greenness over time. Additionally, the paper focuses on the impact of ungulate removal on plant growth and the success of exotic plant species.	frequency of different food items in the deer's diet, as well as measures of diet diversity and trophic niche breadth.
METHODS	a 9-year mix of ground-based field research, time series satellite data, and aircraft imaging spectroscopy and LiDAR years	microhistological analysis of feces. 85pellet groups from 9 sampling points
NON-NATIVE PLANTS	Senecio madagascariensis	vine Lonicera japonica, the trees Morus alba and Robinia pseudoacacia, the shrub Rubus ulmifolius, and the macrophyte Amorpha fruticose, willow trees and poplar trees
UNGULATE SPECIES	ungulates	marsh deer (Blastocerus dichotomus)
HABITAT	subalpine dryland ecosystem	forest planted in mid of the 19th century (wetland system)
COUNTRY	Hawaii	Argentina
AUTHOR	Kellner et al. 2011	Marin et al. 2020

Impact	NEGATIVE	NEGATIVE	NEGATIVE
TYPE OF IMPACT	direct hindrance (browsing)	direct hindrance (browsing)	direct hindrance (browsing preferentially)
Results	Elder (Sambucus nigra; 75-27%) and black locust (75-71%) were the two main browse species in the diet. Additionally, the researchers discovered that each species of browse created distinct patches, where their cover was much higher inside the patch than outside. The tree of paradise was browsed, but not in substantial	Lonicera maackii leaf frequency was much higher in regions where white-tailed deer were banned for four years. These shrubs tended to expand in basal area more quickly over the course of five years, and the ultimate basal area of tiny shrubs was much higher in exclosures.	Deer ingested more biomass from exotic conifers, particularly pine, than from native conifers that they saw frequently, and they consumed the least biomass from those native conifers.
VARIABLES	forest type, rate of the main tree species, age class of nonnative stands, canopy cover of the dominant browse species, and deer diet.	leaf frequency and basal area growth of Lonicera maackii	biomass consumed by human-habituated mule deer. And the number of bites
METHODS	Deer nutrition estimation in 2000 between May and November utilizing a microhistological approach, canopy cover, and habitat use assessment using 3 tagged deer from 1995 to 2001	exclosures: deer’ s were absent for 4 years variables: leaf frequency in (1-1.5m)and (0.5-1m) height. Basal area measure	cafeteria style feeding trail using 13 native and exotic conifers, preference: number of bites taken from each plant sample, weight
NON-NATIVE PLANTS	tree of heaven, black locust,	Lonicera maackii	(Norway spruce, Scots pine and Mugho pine (the most preferred)
UNGULATE SPECIES	red deer	Odocoileus virginianus (white tailed deer)	mule deer
HABITAT	low land non-native forests	natural forests	
COUNTRY	Hungary	USA	USA
AUTHOR	Mátrai et al. 2004	Peebles et al. 2018	Rea et al. 2017

Impact	NEGATIVE	NEGATIVE
TYPE OF IMPACT	Direct hindrance (browsing)	direct hindrance (grazing preferentially)
Results	Inside exclosures, the growth rate of invasive bushes was around 30 times greater.	the most invasive species was preferred, (Pinus contorta).
VARIABLES	growth rate	Physical characteristics (foliar toughness and water content), concentration of anti-herbivory chemical substances (-pinene, -pinene, 3-carene, and resins), browsing frequency, and browsing intensity
METHODS	exclosures/unfenced controls	five exclosures, 480 plant, 400 sheep. Measurement: number of browsed seedlings, height of seedlings, number of defoliated seedlings, probability of survival after treatment, estimating anti browsing
NON-NATIVE PLANTS	invasive shrubs (Rosa multiflora, Ligustrum vulgare, Lonicera maackii, and Berberis thunbergii).	Pinus contorta (most invasive species, P. ponderosa, P. radiata, and P. jeffreyi (least invasive)
UNGULATE SPECIES	white tailed deer	sheep
HABITAT	bottomland forest.	mountainous and steppe
COUNTRY	USA	Argentina
AUTHOR	Shelton et al. 2014	Zamora-Nasca et al., 2020

Impact	NEGATIVE	species specific
TYPE OF IMPACT	direct hindrance (grazing preferentially)	species specific
Results	The results showed that increased herbivory intensity by sheep led to a decrease in the survival and height of Pinus contorta, indicating that Herbivorous animals like sheep can be crucial in preventing the spread of exotic conifers.	higher density of (woody species) in encloser comparing to exclosures , and higher density after culling comparing to before culling the density of (nonnative herbs) were lower in enclosure compared to exclosures
VARIABLES	sheep stocking rates on the damage, height reduction, and survival of Pinus contorta,	Native and non-native vegetation: monitored for changes in abundance and diversity, deer density, stem density, cover as percentage
METHODS	five blocks of enclosures, they grew 42 P. contorta seedlings in each plot. Four sheep density 1×, 2×, 4× and 8×,(number of browsed branches, height before and after	exclosure/enclosure after deer culling (reducing the deer density to o 3.8 km– 2)
NON-NATIVE PLANTS	Pinus contorta	Rosa multiflora ,Berberis thunbergii (Japanese barberry), Rhamnus cathartica (European buckthorn), and Ligustum obtusifolium (border privet) ((woody species)) non-native herbs included Urtica dioica var. dioica (European sting ing nettle), Ficaria verna (lesser celandine), and Alliaria petiolata (garlic mustard),
UNGULATE SPECIES	sheep	
HABITAT		oak-hickory mixed forest And grasslands ,
COUNTRY	Argentina	USA
AUTHOR	Zamora Nasca et al. 2018	Almendinger et al. 2020

Impact	species specific	species specific
TYPE OF IMPACT	species specific	species specific
Results	in the deer access areas the abundance and growth of (Alliaria petiolata and Microstegium vimineum) increased while the abundance and growth decreased for (Lonicera japonica, L. maackii, and R. mule tiflora)	Compared to native plant species, white-tailed deer avoided invasive introduced plant species more often. The kind of plants that deer ate varied, which means avoidance: (Microtegium vimineum, Berberis thunbergii, and Aliaria petiolata) preferred: (Lonicera morrowii, Ligus trum vulgare, and Celastrus orbiculatus)
VARIABLES	richness, and abundance of introduced and native plants	selectivity coefficient of the native herbivore white-tailed deer for different plant species. The proportion of each plant species consumed and how much of each plant species there is in the total biomass available
METHODS	deer-exclusion and deer-access plots	a multiple choice (cafeteria-style) deer chose from 15 plant species
NON-NATIVE PLANTS	Allaria. altissima, A. petiolata and M. vimineum ,Lonicera japonica, L. maackii, and R. mule tiflora	(Alliaria petiolata, Berberis thunbergii, and Microstegium vimineum, Celastrus orbiculatus, Ligus trum vulgare, and Lonicera morrowii
UNGULATE SPECIES	white tailed deer	white-tailed deer (Odocoileus virginianus)
HABITAT		
COUNTRY	USA	USA
AUTHOR	Averill et al. 2018	Averill et al., 2016

Impact	species specific	species specific
TYPE OF IMPACT	species specific	species specific
Results	(Lonicera sp., Elaeagnus sp., and Rubus phoenicolasius) more abundant in the fecal samples than the plot samples. Alliaria petiolata was avoided.	deer Prescence decreased the growth of the non-native species Frangula alnus more than its paired native species Viburnum dentatum.increased E. umbellata open growth r understory survival than its native competitor.no impact on Acer
VARIABLES	Comparsion btween the abundance of the in the local community to the plant DNA traces found in the fecal samples to measure the relative frequency of which native or non-native were consumed by deer	height, basal diameter, biomass (native and non-native plants)
METHODS	metabarcoding approach (PCR amplicons of the plant rbcL gene), collected from fecal samples from 12deer	2 years study, compare 3 pairs of native an non-native plant species (similar in life form and shade tolerance) planted in with/without enclosure. Open/ understory. (manipulative field experiment) .
NON-NATIVE PLANTS	including Alliaria petiolata, Lespedeza sp., Oplismenus hirtellus, Berberis (shrub), Periscaria perfoliatawe and Lonicera sp., Elaeagnus sp., Rubus phoenicolasius, Rosa multiflora	Non-native Acer platinoids, Frangula alnus P Mill. (=Rhamnus frangula L.) and Elaeagnus umbellata
UNGULATE SPECIES	whit tailed deer	white-tailed deer (Odocoileus virginianus) and porcupine (Erethizon dorsatum)
HABITAT	forest	Mount Toby Demonstration Forest, upland hemlock-hardwoods forest
COUNTRY	USA	USA
AUTHOR	Erickson et al., 2017	Knapp et al. 2008

Impact	species specific	species specific	species specific
TYPE OF IMPACT	Species specific	species specific	species specific impact, facilitating the growth and spread of some invasive plant species by browsing on other plant specie
Results	Microstegum vimineum abundance increased with more deer pressure,. Abundance and Grazing on Alliaria petiolata: There was no significant relationship between grazing on Alliaria petiolata and deer pressure.	reduced the cover of Celastrus orbiculatus (oriental bittersweet).no significant effect on the species rich ness.no impact on English ivy, honey suckle	Increased the abundance of all the plants except R. multiflora
VARIABLES	ABUNDANCE AND grazing rate	vegetation thickness and coverage and richness	abundance of native and invasive.
METHODS	the study compared: accumulation rate of fecal pellet, deer brows in native woody species and shrub layer cover. Use it to determine the relationship between deer pressure	17/enclosed 17/ control from 2001-2004,	4hectar exclosure and 4 h reference
NON-NATIVE PLANTS	Microstegum vimineum and Alliaria petiolata	Cilantros orbiculatus (oriental bittersweet). English ivy, honey suckle	Rosa multiflora, Berberis thunbergii, Rubus phoenicolasius and Microstegium vimineum
UNGULATE SPECIES	white tailed deer	Odocoileus virginianus (white-tailed deer)	Odocoileus virginianus (white tailed deer))
HABITAT	fragmented suburban forests	mixed forest of oak-beech	temperate forest
COUNTRY	USA	USA	USA
AUTHOR	Morrison et al., 2022	Rossell et al. 2007	Shen et al. 2016

Impact	species specific	no impact
TYPE OF IMPACT	species specific	no impact
Results	the density of Adiantum hispidulum (fern), increased in fenced plots, Blechnum appendiculatum (fern) increased then decreased, Lantana camara (shrub) no significant change	no significant effect of ungulates on non-native plant species in the forested rangelands
VARIABLES	density of native and alien overstory canopy trees, as well as the density of small individuals of native and alien canopy species in the understory. The density of native herbaceous and understory shrub species	change in overall native plant cover, exotic plant cover, native plant richness, exotic plant richness and richness and cover of the individual exotic and native plant guilds.
METHODS	fenced/unfenced plots over 15 years study (observational)	seven-year experiment in both managed and unmanaged forest stands and recorded changes in plant life form richness and cover in experimental plots that were grazed only by cattle, only by elk, or not grazed by any ungulate (observational)
NON-NATIVE PLANTS	Adiantum hispidulin (fern) Blechnum appendiculatum (fern) Lantana camara (shrub)	in general,
UNGULATE SPECIES	invasive ungulates	non-native cattle and native elk herbivores
HABITAT	diverse mesic forest on Kauaʻ i	in forested rangelands in Northeastern Oregon
COUNTRY	Hawaiian Islands	USA
AUTHOR	Weller et al., 2018	Pekin et al. 2016

Annex (2) shows different data obtained from the publications to analyze the non-native plants impact on ungulate species.

Impact	NEGATIVE	NEGATIVE
TYPE OF IMPACT	**population decline** (the abundance of ungulates decreased when the abundance of invasive plants increased)	**Habitat degradation** (Prescence and habitat use were decreased in the Prescence of the invader)
METHODS	sign survey and observation, using google earth app to determine the grids and sample points, tracking by GPS, variables measured (canopy cover, habitat types, invasive species coverage, ungulates (direct observation or dropping)	Using motion-triggered infrared cameras, the researchers surveyed sites with and without buckthorn to indicate the deer Prescence, observational methods
NON-NATIVE PLANTS	(Mikania micrantha, Chromolaena odorata, Lantana camara, and Parthenium hysterophorus)	common buckthorn (Rhamnus cathartica L.) shrub
UNGULATE SPECIES	(Deer and wild pigs)	white tailed deer (Odocoileus virginianus Zimmermann)
HABITAT	different types of forests (Mixed Forest, sal forest, Riverine Forest) and grass land	forest preserves and natural areas
COUNTRY	Nepal	USA
AUTHOR	Adhikari et al. 2022	Heneghan et al. 2006

Impact	NEGATIVE	NEGATIVE	POSITIVE	POSITIVE
TYPE OF IMPACT	**food scarcity** (impact through reducing the feeding rate)	**Habitat degradation** (habitat use declined in the infested areas)	**reproductive enhancement** (correlation between deer birth rate) number of births per season) and exotic fruit fall, on- seasonal birth maybe correlated with long exotic species fruit span)	**population increase** (the increased abundance of the ungulates associated with the invasive Prescence)
METHODS	behavioral observation: (focal animal sampling) feeding and stepping rate, as well as L. camara invasion, canopy cover, browse density, and percentage grass cover	pallet -groups density (for habitat use), twig count and measurement (for deer browse), 4 infested and 4non- infested habitat	enclosure 18h, 10-14 animals, from 1998 to 2001, (date of birth, rainfall, fall of fruit)	The study used camera-trap surveys to collect data on the occurrence of the animals. The surveys were conducted over 8633 trap-days, (modeling method)
NON-NATIVE PLANTS	Lantana. Camara	Leafy spurge (Euphorbia esula), smooth brome (Bromus inermis), Japanese brome (B,	peach (Prunus persica), mulberry (Morus alba and M. nigra), and guava (Psidium guajava).	exotic pine
UNGULATE SPECIES	elephants	bison (Bos bison), elk (Cervus elaphus), deer (Odocoileus spp.)	brown brocket M. gouazoubira	red deer, Cervus elaphus; wild boar, Sus scrofa.
HABITAT	dry deciduous forest	mixed grass prairei, and forests (in the flood plains and slops areas)	montane forest	a transition between Austrocedrus chilensis forest and arid stepp
COUNTRY	India	USA	Argentina	Argentina
AUTHOR	Kishore et al. 2022	Trammell and Butler 1995	Juliá and Peris 2010	Lantschner et al. 2013

Impact	POSITIVE	POSITIVE	POSITIVE	POSITIVE
TYPE OF IMPACT	**habitat enhancement** (non-native forests can provide suitable feeding and hiding habitats for red deer)	**dietary shift** (The non-natives made up 45-78% of Samber diet in grasslands and 43-60% in the forest.in spring and summer)	**dietary shif**t (the main browse in fall and winter ONLY)	**dietary shift** (providing a food source during a time when other preferred foods are scarce (EARLY SPRING))
METHODS	deer diet estimation using micro histological method in 2000 between may and November, canopy cover, habitat use evaluation using 3 marked deer from 1995-2001	quantitative fecal analysis	rumen samples analysis of 146 deer, crude protein content from privet	plots in 8 sites, transect sampling for twig abundance and percent of twigs browsed, from this they calculated deer preference using the electivity index
NON-NATIVE PLANTS	tree of heaven, black locust,	Pennisetum spp (10–39%) Pennisetum clandestinum and P. glabrum,	privet (Ligustrum sinense)	Amur honeysuckle Lonicera maackii
UNGULATE SPECIES	red deer	sambar (Cervus unicolor)	white tailed deer	White tailed deer (Odocoileus virginianus Zimmermann)
HABITAT	low land non-native forests	grassland and forests	Forests dominated by oaks (Quercus spp.), hickories (Carya spp.), and pines (Pinus spp.)	broadleaf deciduous forest
COUNTRY	Hungary	Sri Lanka	USA	USA
AUTHOR	Mátrai et al. 2004	Padmalal et al. 2003	Stromayer et al. 1998	Wright et al. 2019

Annex(3) shows the selective behavior of ungulates towards non-native plant species.

UNGULATE SELECTIVTY TWORDS	yes	yes	yes	NO	No
METHODS	Jacobs' selectivity index (positive value)	cafeteria experiment	cafeteria experiment	cafeteria experiment	electivity index (negative value)
LIFE FORM	tree	trees	shrubs	trees	shrub
EXOTIC PLANT SPECIES	Robinia pseduacacia	(Norway spruce, Scots pine and Mugho pine	Celastrus orbiculatus, Ligus trum vulgare, and Lonicera morrowii	Pseudo Suga menziesii and Pinus ponderosa	Amur honeysuckle [Lonicera maackii]
UNGULATES TYPE	Red deer	mule deer	white-tailed deer (Odocoileus virginianus)	Cervus elaphus [elk or red deer], Dama dama [fallow deer] and Axis axis [axis deer]	White tailed deer (Odocoileus virginianus Zimmermann)
COUNTRY	Hungary	USA	USA	Argentina	USA
AUTHORS	Katona et al. 2013	Rea et al. 2017	Averill et al. 2016	Nuñez et al. 2008	Wright et al. 2019

Annex (4) shows the species- specific impact of ungulates on different plant species

	Plant Species	Deer Impact	Variable Affected	Impact Direction
Rossell et al., 2007	Cilantros orbiculatus	Reduced	Vegetation thickness, coverage, and richness	Negative
	English ivy	No impact	Vegetation thickness, coverage, and richness	No impact
	Honeysuckle	No impact	Vegetation thickness, coverage, and richness	No impact
Averill et al. 2018	A. altissima	no impact	Abundance and growth	No impact
	A. petiolata	increased	Abundance and growth	Positive
	M. vimineum	incresed	Abundance and growth	Positive
	L. japonica	Reduced	Abundance and growth	Negative
	L. maackii	Reduced	Abundance and growth	Negative
	R. multiflora	Reduced	Abundance and growth	Negative
Knapp, et al. 2008	Acer platinoids	No Impact	Height /Basal diameter/Biomass	No impact
	Frangula alnus	Reduced	Height /Basal diameter/Biomass	Negative
	Elaeagnus umbellata	Increased	Height	positive
Almendinger et al. 2020	Rosa multiflora	Reduced	Density	Negative
	Berberis thunbergii	Reduced	Density	Negative
	Rhamnus cathartica	Reduced	Density	Negative
	Ligustrum obtusifolium	Reduced	Density	Negative

	Plant Species	Deer Impact	Variable Affected	Impact Direction
Almendinger et al. 2020	Urtica dioica var. dioica	Increased	Density	Positive
	Ficaria verna	Increased	Density	Positive
	Alliaria petiolata	Increased	Density	Positive
Shen et al. 2016	Rosa multiflora	Decreased	Abundance	Negative
	Berberis thunbergii	Increased	Abundance	Positive
	Rubus phoenicolasius	Increased	Abundance	Positive
	Microstegium vimineum	Increased	Abundance	Positive
Morrison et al. 2022	Microstegum vimineum	Increased	Abundance	Positive
	Alliaria petiolata	No impact	Abundance	No Impact
Weller et al. 2018	Adiantum hispidulin	Reduced	Density	Negative
	Blechnum appendiculatum	mixed	Density	Negative → positive
	Lantana camara	No impact	Density	No significant change
Averill et al. 2016	Alliaria petiolata	Avoided	Proportion of each plant species consumed by deer	Positive
	Berberis thunbergii	Avoided	Proportion of each plant species consumed by deer	Positive
	Microstegium vimineum	Avoided	Proportion of each plant species consumed by deer	Positive
	Ligus trum vulgare	Preferred	Proportion of each plant species consumed by deer	Negative

	Plant Species	Deer Impact	Variable Affected	Impact Direction
Averill et al. 2016	Lonicera morrowii	Preferred	Proportion of each plant species consumed by deer	Negative
Erickson et al., 2017	Lonicera sp.	Consumption	Abundance (comparing between local community and feces)	Negative
	Elaeagnus sp.	Consumption	Abundance	Negative
	Rubus phoenicolasius	Consumption	Abundance	Negative
	Alliaria petiolata	Avoidance	Abundance (comparing between local community and feces)	Positive

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