Bark-stripping of Common Buckthorn by Goats During Managed Browsing on Bur Oak Savannas

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Research Article

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Abstract

Goats are being used increasingly to manage woody invasive plants in woodland habitats, but their specific impacts on those plants over a period of time during active, periodic browsing has not been documented. This study investigated bark-stripping by goats browsing on common buckthorn in savanna habitats, focusing on possible size-selective feeding and the cumulative effects of repeated, periodic browsing over a 3-year period. When surveyed after the first browsing period, bark was stripped selectively on buckthorn stems 20 to 60 mm in diameter. Approximately 60% of all stripped stems were completely girdled, but only 14-17% of stems were bark-stripped. After five browsing periods, 66% of standing stems displayed bark stripping and 39% were completely girdled. Buckthorn densities were reduced by 90% compared to the first browsing period, the decline resulting mostly from consumption of foliage and terminal shoots of small (<20 mm) buckthorn and bark-stripping resulting in top-kill in intermediate-sized (20-60 mm) plants. Large buckthorn (>60 mm) were largely unimpacted by goats. Relatively few (28%) seedling buckthorn were browsed by goats, although >90% of 2nd-year plants were browsed. Buckthorn can be managed in part via goat browsing, but repeated, periodic browsing over several to many years may be necessary to produce a significant impact, and other techniques will be needed to eliminate large, seed-producing plants.

Introduction

Domestic goats (*Capra aegagrus hircus* L.) have long been used to manage undesirable vegetation (Taylor 1992; Hart 2001). Their willingness to consume and tolerate a diversity of plants often makes goats a top choice among various livestock for vegetation management (Hart 2012). Recently, the ability of goats to feed aggressively on invasive woody shrubs has produced new and dramatically expanding agricultural and business opportunities using goats to manage unwanted vegetation (Hart 2001; Jenner 2013; Fernandez 2012; Nolden 2020). Goats can defoliate woody invasive plants and strip bark from their stems (Hart 2001, 2012), although it may require several years of repeated, managed browsing to suppress most woody shrub species (Gipson 2005). A recent study (Nolden 2020) suggests that using goats as the only management technique will not produce rapid control or complete eradication of woody shrubs.

Savanna habitats, especially remnant patches, are prone to invasion by woody shrubs due to their high edge-to-size ratio, frequent use by fruit- and seed-eating birds, and removal of fire and large ungulates (O'Connor 2006; Harrington and Kathol 2009). The takeover of savannas by woody invasives (e.g., buckthorns [*Rhamnus* spp.], honeysuckles [*Lonicera* spp.]) is especially concerning, given the importance of these habitats to numerous threatened, endangered, and special-concern species and the significant loss (> 90% decline from 1890s to present) of savanna habitat in some regions (MN DNR 2006). Buckthorn is especially problematic as the most frequently reported invasive plant in these regions and likely one of the most ecologically and economically damaging non-native plants (Russell et al. 2020). Goats readily consume buckthorn, even dense stands of plants growing in difficult terrain (Hart 2012;

Jenner 2013). Consequently, using goats to help restore savannas is becoming commonplace on both public and private lands (Nolden 2020).

Despite the increasing use of goats to manage woody invasive shrubs in savannas and other habitats, scientific data on the impact of goat browsing (from here forward defined as including defoliation, terminal shoot removal, and bark stripping) on woody invasive plants is only just emerging (Marchetto et al. 2020; Nolden 2020; Russell 2020). Managed goat browsing can produce significant increases in dead and top-killed woody invasives (Nolden 2020), and goat digestion effectively destroys buckthorn seeds (Marchetto et al. 2020). However, the process by which goats kill buckthorn, honeysuckle, and other woody invasives is documented only through anecdotal observations (Nolden 2020). No scientific studies have examined the specific impacts of goat browsing on buckthorn (either individual plants or populations), or directly measured these impacts over a period of time during active, managed browsing with goats. Consequently, the objective of this study was to assess the impact of initial and repeated browsing by goats on invasive European buckthorn within a ridgetop oak savanna complex in the blufflands of southeastern Minnesota. Specifically, it was hypothesized that 1) goats would exhibit size-selective feeding (bark stripping) on buckthorn plants where the top foliage was out of reach of goats, and that 2) repeated browsing over 3 years would significantly suppress buckthorn densities through a combination of defoliation, terminal bud removal, and girdling with subsequent sucker (or basal sprout) browsing.

Study Site

Garvin Heights Park and Overlook (44° 02’ 04” N, 91° 39’ 05” W), jointly owned and maintained by the City of Winona, MN, and Winona State University, consists of a patchy distribution of bur oak savannas and dry bluff prairies bordered by oak-hickory and maple-basswood forests. All habitats were invaded by Tatarian honeysuckle (*Lonicera tatarica* L.) and European buckthorn (*Rhamnus cathartica* L.) during the 1980s, with subsequent efforts made to control invasive shrubs only within the dry bluff prairie and a small section of savanna nearest a public overlook. Savannas and prairies at Garvin Heights have a WSW aspect and a slope of approximately 20°.

In 2016, a 3-year project was undertaken to reclaim invaded savanna and prairie habitats via a combination of goat browsing (contracted from Diversity Landworks LLC, La Crescent, MN; https://www.diversitylandworks.com), cutting and treatment with chemical herbicide, and prescribed fire. To begin reclamation, buckthorn and honeysuckle in two parcels (Parcel 1 [0.75 hectare] - savanna only; Parcel 3 [0.61 hectare] - savanna and prairie) were first subjected to goat browsing, whereas in one other parcel (Parcel 2 [1.08 hectares] - savanna only) plants were first cut and treated. Plants in Parcel 1 were only treated by browsing throughout the project period, but all three treatments were applied in various combinations within Parcels 2 and 3. For this study, savanna habitats within Parcels 1 and 3 were used to examine the effects of an initial, single period of goat browsing on buckthorn, with Parcel 1 also used to assess the cumulative effects of five periods of goat browsing on buckthorn. During each browsing period, 35 to 80 goats were confined to the parcel by portable electrified fencing for a period of 5 to 7 days, under the direct supervision of contractor personnel.

Methods

Effects of first browsing

Immediately following the first period of goat browsing during October/November 2016, buckthorn densities, size distributions, and browsing damage were assessed in the savannas of Parcels 1 and 3. Densities of buckthorn (5 to 150 mm stem diameter) in Parcels 1 and 3 were assessed with short (10–20 m) belt transects and small (2 m^2) plots, respectively. Transects were used in Parcel 1 where buckthorn were larger and more dispersed, whereas plots were used in Parcel 3 where higher buckthorn densities made transects impractical. Replicate plots (n = 13) and transects (n = 12) were selected at random using coordinate grids within each habitat. Plot boundaries were delineated with a collapsible plot frame, and belt transects were sampled with a meter tape and metric measuring rod following the King procedure (Brower et al. 1998).

Densities of and browsing damage (i.e., missing foliage and/or terminal shoots) to small buckthorn (1st -year seedlings and 2nd -year plants) were assessed in 40 random plots (0.1 m^2) in Parcel 1 after the first browsing period. Seedlings and 2nd -year plants were tallied separately, and the proportions of plants that were browsed in each age group were determined for each plot.

In addition to consuming buckthorn foliage within reach, goats stripped and consumed bark from buckthorn and other shrubs/trees within the Garvin Height parcels. Consequently, evidence of bark stripping was used as an indicator of browsing damage to buckthorn. All buckthorn within plots and belt transects were categorized as browsed or not browsed, and individual browsed stems (those within plots and transects, plus 150 to 220 additional plants per parcel) also were assigned to five different categories based on the extent of bark-stripping damage: bark stripping covering 1 to 25% of the stem's circumference, 26 to 50%, 51 to 75%, 76 to 99%, and 100%.

To assess buckthorn size distributions and possible size-selective bark stripping by goats, stem diameters of bark-stripped and non-bark-stripped buckthorn in Parcels 1 and 3 were measured with a dial caliper (nearest mm) at a height (50 to 75 cm above ground level) consistent with the height of most bark stripping. The goal was to measure 300 and 500 plants within each parcel to obtain a representative size distribution for both bark-stripped and non-bark-stripped stems.

Effects of multiple browsings

After the final (fifth) browsing for the project, the effects of goats on buckthorn density, possible size-selective bark stripping, and potential for long-term buckthorn control were assessed in Parcel 1. Densities of live buckthorn > 5 mm stem diameter were assessed in replicate plots (each 20 m^2, n = 30) arranged in three parallel transects along the top, middle, and bottom of the hillslope, respectively.

Diameters of at least 450 plants were measured as described above to determine size distributions of bark-stripped and non-bark-stripped plants, and the extent of bark-stripping damage (% of circumference in five categories as above) was assessed. Thirty, 1-m^2 plots were used to assess densities of 1st -year seedlings and 2nd -year plants within Parcel 1. Unlike after the initial browsing, no attempt was made to differentiate browsed and non-browsed plants. Finally, diameters were measured for individual buckthorn plants > 5 mm stem diameter in each of four possible fate categories: 1) entirely dead due to complete girdling/bark stripping by goats, 2) top-killed by complete girdling/bark stripping by goats, but with live basal sprouting, 3) partial girdling/bark stripping by goats, but tops still living, and 4) no bark stripping by goats and tops alive. Measurements were made until 90 + buckthorn had been tallied in each category.

Analyses

After initial goat browsing, buckthorn in Parcels 1 and 3 were compared to assess possible differences in plant density and size between parcels, and to examine possible size-selective feeding by goats. Buckthorn densities and stem diameters were compared between parcels with Mann-Whitney tests, and diameter size distributions were compared between sites with a contingency table after grouping measurements into 10-mm size categories. Within each parcel, stem diameters and diameter size distributions were compared between bark-stripped and non-bark-stripped buckthorn stems with Mann-Whitney tests and contingency tables, respectively, to determine if goats exhibited size-selective feeding within individual habitats. Similarly, diameters and size distributions of bark-stripped stems were compared between parcels to determine if goats fed on similar-sized buckthorn in habitats where buckthorn populations may have different age/size distributions.

After five browsings by goats, densities, mean sizes, and size distributions of buckthorn in Parcel 1were compared to data gathered after the initial browsing, and size distributions of buckthorn in different fate categories were assessed. Densities and mean sizes of buckthorn were compared after first and fifth browsings with Mann-Whitney tests, and size distributions were compared with a contingency table test. Similar comparisons also were made between live and dead buckthorn and bark-stripped and non-bark-stripped buckthorn after the fifth browsing. Separate single-factor analysis of variance tests were used to compare diameters of buckthorn among the bark-stripped categories (% of circumference), and among the four fate categories described above.

Results

Effects of first browsing

Goats had a noticeable effect on buckthorn in both Parcels 1 and 3 after their initial browsing, reducing foliage within ~ 1.5 m of the ground. During browsing, goats consumed most of the buckthorn leaves and stem tips within easy reach. To reach higher forage, goats either propped their front feet up against larger stems or forced plants toward the ground by using their legs and bodies to bend flexible stems. In addition to consuming foliage, goats stripped bark from stems of buckthorn and other shrubs and saplings (Fig. 1). Buckthorn seedlings and 2nd -year plants were still abundant after browsing, with > 25% of seedlings and > 90% of 2nd -year plants displaying evidence of browsing (Table 1).

Although buckthorn populations on the two savanna parcels at Garvin Heights differed significantly both in density ($U_{13,12}$ = 156, $P < 0.0001$; Fig. 2) and stem diameter ($U_{483,324}$ = 27,068, $P < 0.0001$; Fig. 3A), goats exhibited similar size-selective bark stripping on buckthorn stems in both habitats after a single browsing (Fig. 3B, C). In general, goats selectively stripped bark from stems 20–49 mm in diameter (54.4% of all buckthorn) when available, selecting against stems < 20 mm (43.4% of all buckthorn) and > 60 mm (2.2% of all buckthorn) in diameter. Similar, low proportions of stems were bark-stripped (17% and 14%, $U_{13,12}$ = 58, $P = 0.145$) in both habitats, with goats bark stripping selectively on significantly larger stems than those left unstripped in both habitats (mean ± SD; Parcel 1: bark stripped 32 ± 11 mm, unstripped 28 ± 16 mm, $U_{251,232}$ = 38,027, $P < 0.0001$; Parcel 3: bark stripped 19 ± 4 mm, unstripped 13 ± 3 mm, $U_{177,147}$ = 2956, $P < 0.0001$). Bark stripped stems differed significantly in size between parcels ($U_{232,177}$ = 4753, $P < 0.0001$; Fig. 2B, C), directly corresponding to differences in sizes of stems available in the two parcels.

The majority (> 60%) of buckthorn stems that were bark stripped by goats were completely girdled in both savanna parcels after the first browsing (Fig. 4). The extent of bark stripping did not differ between parcels (X^2_4 = 0.72, $P = 0.949$). Since complete girdling should either kill or top-kill buckthorn stems, and 14–17% of stems experienced some degree of bark stripping, the initial browsing by goats in the two savanna parcels potentially either top-killed or completely killed 9–11% of buckthorn within the parcels.

Effects of repeated browsings

After five browsings conducted over a 31-month period, dead and top-killed buckthorn were common in Parcel 1, and overall densities of standing buckthorn (> 5 mm stem diameter) were reduced by 90% compared to densities assessed after the initial browsing ($U_{30,13}$ = 390, $P < 0.0001$; Fig. 2). Many buckthorn were lying dead on the ground, apparently knocked down and killed by browsing goats. The proportion of buckthorn stems bearing evidence of bark stripping was nearly 4X that observed after the initial browsing (66% versus 17%), but one-third of buckthorn stems still remained unstripped after five browsings. The proportion of stems in most various bark-stripping categories nearly doubled and differed significantly after five versus one browsing (X^2_4 = 49.4, $P < 0.001$; Fig. 5), whereas the proportion of completely girdled plants declined by more than one third. However, 39% of all buckthorn stems had been completely girdled by goats after five browsings, compared to 11% after the initial browsing. After five browsings, buckthorn with stem diameters < 20 mm represented only 8% (65 of 820 stems measured) of standing stems.

In contrast to larger buckthorn, densities of seedling and 2nd -year buckthorn were not reduced after multiple browsing periods (Table 1). Seedling densities after five browsings were > 60% higher than after the initial browsing, a significant increase. Densities of 2nd -year plants were not significantly different when compared to densities immediately after the initial browsing period.

Mean (± SD) stem diameters of bark stripped (32 ± 13 mm) and unstripped (33 ± 16 mm) buckthorn did not differ significantly ($U_{299,152}$ = 22,630, P = 0.472) after five browsings. Likewise, there were no significant differences in stem diameters among % bark-stripping categories (ANOVA $F_{4,295}$ = 1.14, P = 0.333). However, significant size-selective bark stripping was still evident after five browsings (X^2_6 = 43.2, P < 0.001), with goats selectively stripping bark on stems 20–49 mm while rejecting stems < 20 mm and > 50 mm (Fig. 6). However, stem diameters differed significantly among fate categories (ANOVA $F_{3,364}$ = 35.65, P < 0.0001), with dead and top-killed/basal sprouting buckthorn on average 30–40% smaller than either unstripped or incompletely girdled stems (Fig. 7A). A large proportion (30–45%) of these unstripped or incompletely girdled stems were > 50 mm in diameter (Fig. 7B), too tall for goats to browse foliage and too large for goats to bend or push over.

Discussion

This study found five important effects of goat browsing on buckthorn after either a single browsing period or after repeated browsings. First, goats exhibited size-selective feeding when stripping bark from buckthorn stems. Second, goats girdled approximately 60% of the stems strip barked, but a large majority of stems were not stripped during an initial browsing. Third, repeated browsing reduced densities of buckthorn > 5 mm stem diameter by 90% by killing the abundant, smaller buckthorn within the population. Fourth, goats browsed on seedling and 2nd -year buckthorn, but did not reduce their densities after five browsings. Finally, goats did not kill most large (> 60 cm diameter) buckthorn, as they were unwilling or unable to strip bark from larger stems.

Size-selective bark stripping by goats on buckthorn was evident after both an initial period of browsing and after five periods of browsing. Goats stripped bark and girdled buckthorn stems primarily within the 20–50 mm diameter range, which comprised the majority of buckthorn present on the savanna sites. Smaller (< 20 mm diameter) plants were seldom bark stripped even though they represented > 40% of buckthorn present; observations suggested that small stems were not stiff enough for easy gnawing, and goats could straddle and bend these plants to access foliage and terminal buds. Larger stems were less frequently bark stripped, likely the result of decreased bark palatability in older or larger trees/shrubs (Bergström 1992; Gill 1992a). Similar, size-selective bark stripping on young tree stems has been observed in red deer (*Cervus elaphus*) in Sweden (Månsson and Jarnemo 2013).

Over 60% of buckthorn stems stripped by goats during the initial browsing session were completely girdled, producing at least top-kill (if not complete kill) of those plants. This magnitude of girdling via bark stripping by browsing wildlife can result in rapid death of browsed woody trees and shrubs (e.g., Michael 1987; Akashi and Nakashizuka 1999). With only 14–17% of stems bark stripped after initial goat browsing, possibly only 11% of total buckthorn stems in the Garvin Heights savannas faced death or top-kill from bark stripping. However, since most bark stripping was focused on stems 20–60 mm in diameter, goats potentially girdled 25–30% of buckthorn stems within that size group. Killing or suppressing this proportion of buckthorn after a single browsing period is significant, as buckthorn in this size group often represent the majority of fruiting stems in buckthorn populations (Delanoy and Archibold 2007). If this result is typical, and goats continue this level of bark-stripping effort during additional repeated browsings, significant reductions in reproductive output of buckthorn can be achieved.

After five browsing episodes, goats reduced buckthorn stem densities by 90% compared to densities assessed after the initial browsing. This likely was achieved through a combination of girdling and killing of stems 20–60 mm in diameter and bending and defoliating plants with stem diameters < 20 mm. Buckthorn stems < 20 mm in diameter declined from 43% of the population immediately after the initial browsing to only 8% after five browsings, suggesting that goats were very successful at defoliating and killing the smaller stems, similar to the effects of other browsers on smaller woody plants (Gill 1992b; Akashi and Nakashizuka 1999; Horsley et al. 2003; Royo et al. 2010). In addition, continued bark stripping during repeated browsing sessions left only one-third of buckthorn stems unstripped after five browsings. Such cumulative bark stripping is typical when young woody stems are subjected to intense feeding pressure from ungulates, often when alternative foods are limited or unavailable, or when additional fiber is needed in the diet (Gill 1992a). Observations during the current study suggest that goats initially consumed a combination of buckthorn foliage, branch tips, and bark when first released into a new habitat, switching more to bark stripping after the other food resources were reduced. By defoliating buckthorn < 20 mm in diameter and stripping bark from larger stems, goats were successful in killing the majority of buckthorn that were present initially within the savanna habitat.

Densities of very small buckthorn (seedling and 2nd -year plants, < 0.5 mm stem diameter) were not reduced by goat browsing. Even though goats browsed on > 90% of 2nd -year plants and > 25% of seedlings, densities were not suppressed over the 3-year period, with seedlings actually becoming more abundant. This suggests the presence of an abundant seedbank, supplying more new plants each year than periodic browsings could control. Goats typically do not browse near the ground, where they may ingest eggs of harmful parasites (Hart 2001), and goat contractors usually remove goats from habitats before ground-level browse becomes the only food option (K. Johnson, Diversity Landworks LLC, personal communication). Conditions for germination of the buckthorn seedbank apparently improved as densities of intermediate-sized (5–60 mm stem diameter) buckthorn were reduced by goats during repeated browsing (Hart 2012). A similar increase in seedling buckthorn density was observed in an adjacent savanna parcel (Parcel 2), where buckthorn had been removed by cutting/treating followed by attempted control of new growth via prescribed burns and propane weed torches. It appears that goats are not effective against very young buckthorn, only browsing on it heavily once it grows beyond the seedling stage. If a buckthorn seedbank is present, or if large buckthorn remain and continue to produce seeds, periodic goat browsing will be necessary to keep the plants in check until the seedbank is depleted and/or the mature buckthorn are removed.

Repeated managed browsings by goats over a period of three years had little to no effect on larger (> 60 mm stem diameter) buckthorn within the Garvin Heights savanna. Goats were unable to access foliage or terminal buds (usually 3 m or more aboveground) on these plants, and were unwilling or unable to strip bark from these larger stems. Even though large buckthorn represented only slightly more than 2% of the buckthorn population in the Garvin Heights savannas, this size group included the major berry- and seed-producers within the population. Inability of goats to feed on large buckthorn was not unexpected, as goat contractors generally recommend felling or otherwise pretreating large buckthorn prior to goat browsing (Hart 2012; Nolden 2020; K. Johnson, Diversity Landworks LLC, La Crescent, MN, personal communication). Because goats likely are ineffective on large buckthorn, using goats along with other practices to control woody invasives would improve the chance of successful management (Nolden 2020).

Management implications

Managed browsing with goats proved to be an effective tool for suppressing established populations of common buckthorn within bluffland savannas in southeastern Minnesota. Suppression was accomplished through 1) direct consumption of foliage and terminal shoots on small buckthorn (< 20 mm stem diameter) that goats could reach or bend over, and 2) bark-stripping of intermediate-sized (20–60 mm) stems that often resulted in complete girdling and eventual top-kill. Girdled and top-killed plants often produced basal sprouts, which goats readily browsed, leading ultimately to complete plant death.

Although goats were successful at eliminating most buckthorn with stem diameters between 5 and 60 mm, they were ineffective against both seedling buckthorn and plants with stem diameters > 60 mm. Prior to using goats to manage buckthorn, all large plants should be felled or chemically treated to eliminate on-going seed production. If a substantial buckthorn seedbank is present, goat browsing will open up the habitat and likely accelerate seed germination, favorably leading to more rapid depletion of the seedbank (Hart 2012). However, during that depletion process that could last from 2 to 6 years (Zouhar 2011), periodic goat browsing will be needed to cull plants as they reach browsable sizes. Managing buckthorn and other woody invasives using goats will be a multi- to many-year undertaking, and landowners should be fully aware that additional control methods will be necessary to successfully suppress and control undesirable vegetation like buckthorn.

Declarations

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Conflicts of interest/Competing interests None

Ethics approval Not applicable

Availability of data and material Data available from the first author

Authors' contributions Both authors contributed to the study conception and design, and collected and analyzed field data. Neal Mundahl wrote the first draft of the manuscript.

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Figures

Figure 1

A goat stripping bark from a common buckthorn stem on a savanna at Garvin Heights Park

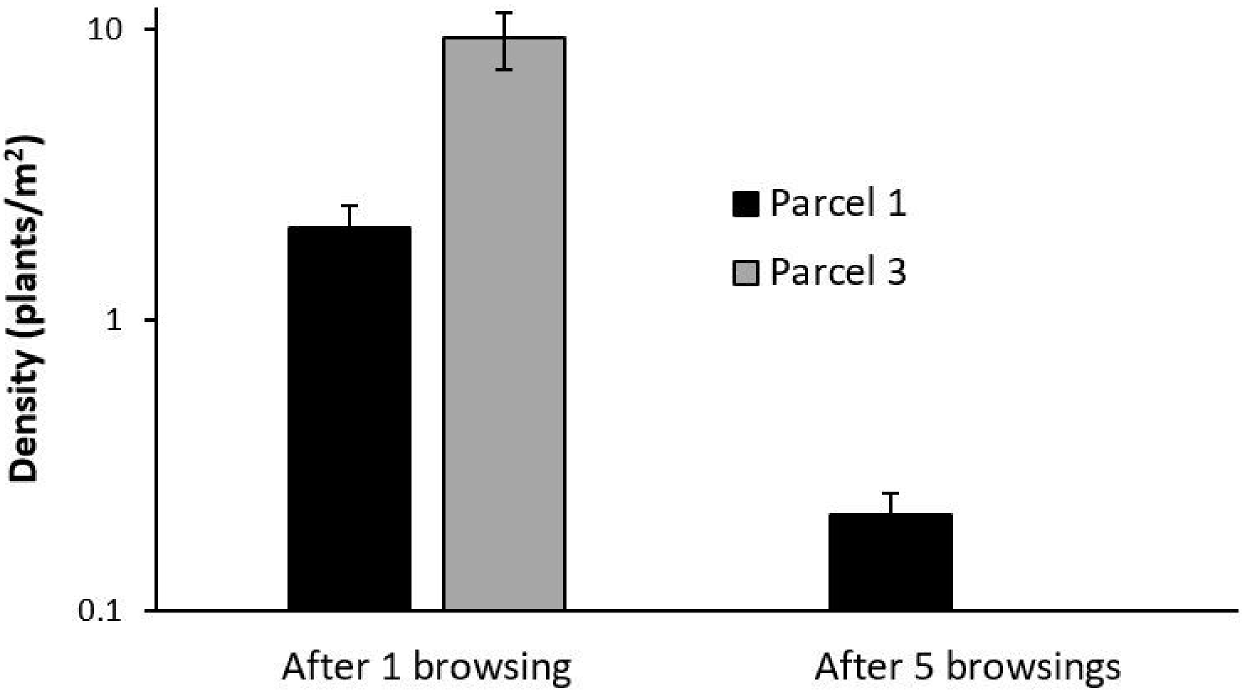

Figure 2

Mean densities of common buckthorn in two savanna parcels after one and five browsing periods. Error bars represent ± 1 SD

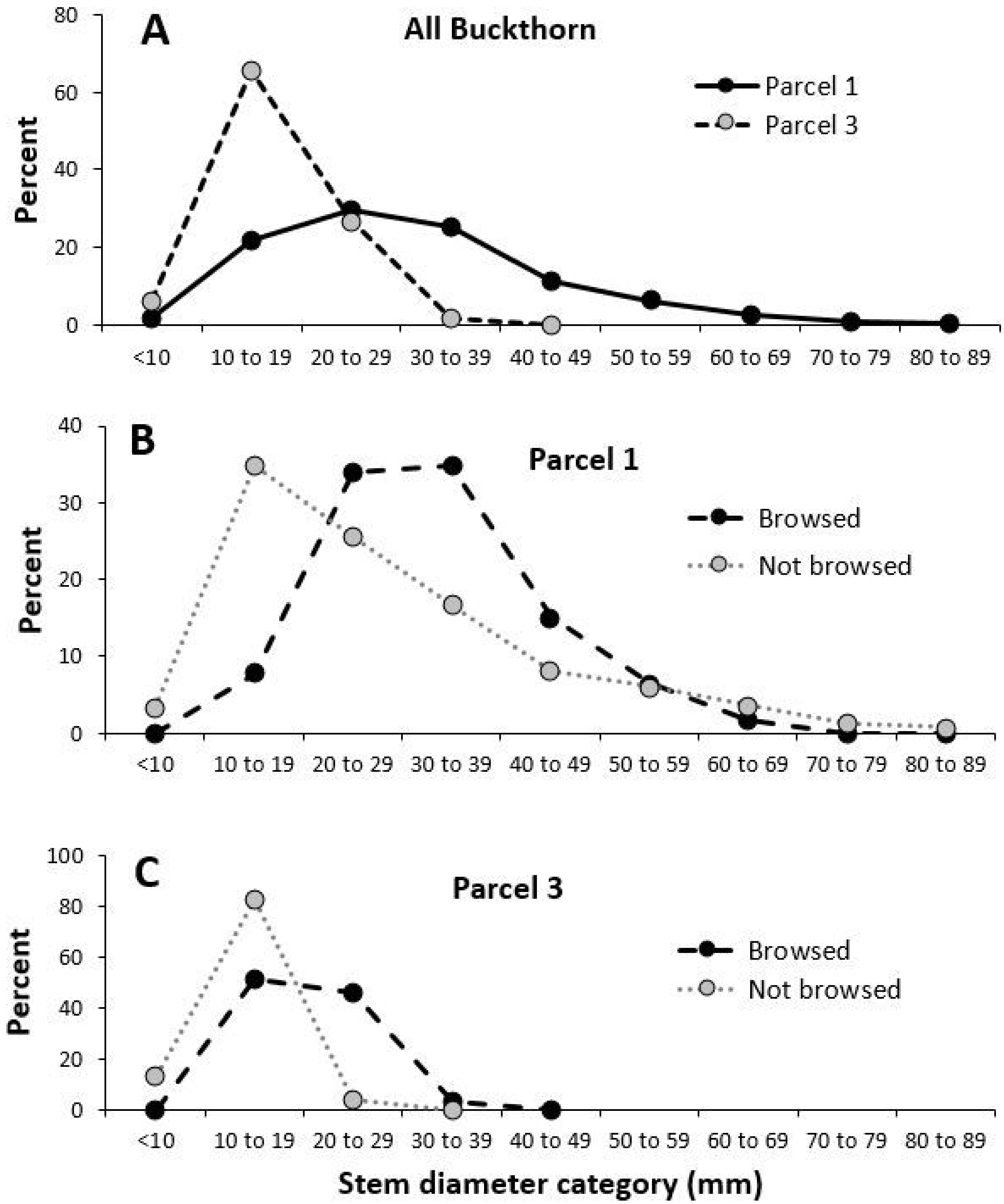

Figure 3

Stem diameter size distributions of common buckthorn in two savanna parcels after a single browsing period. A) Size distributions of all buckthorn in Parcels 1 and 3. B) Size distributions of browsed and non-browsed buckthorn in Parcel 1. C) Size distributions of browsed and non-browsed buckthorn in Parcel 3

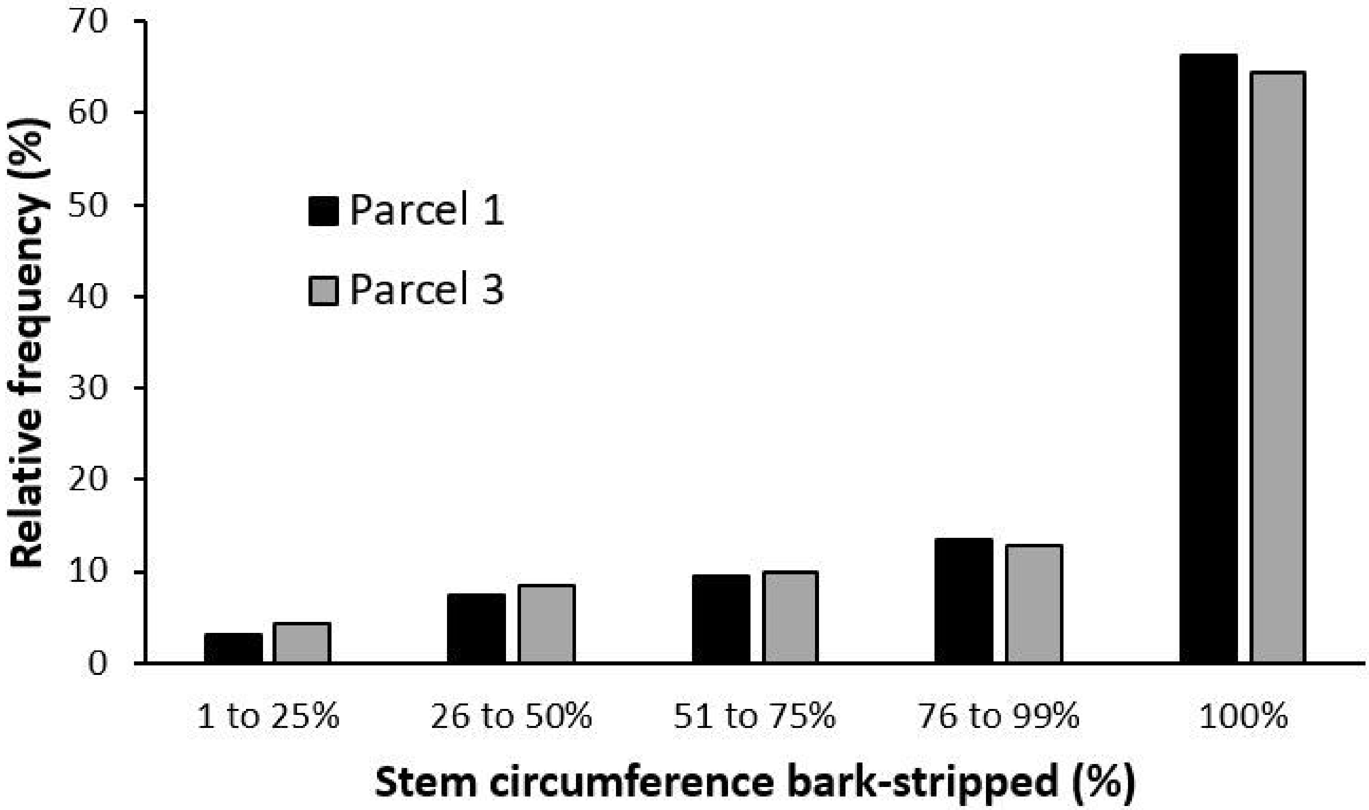

Figure 4

Distributions of bark-stripped common buckthorn stems by degree of bark stripping in two savanna parcels

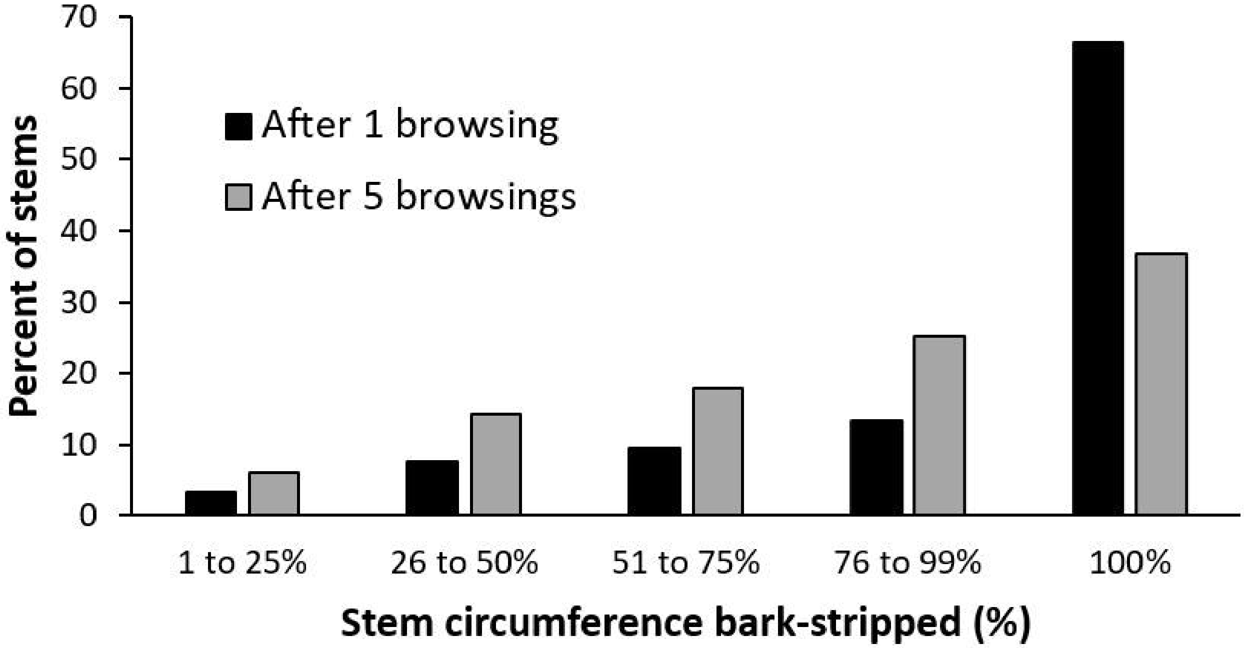

Figure 5

Distributions of bark-stripped common buckthorn stems by degree of bark stripping after one and five browsing periods

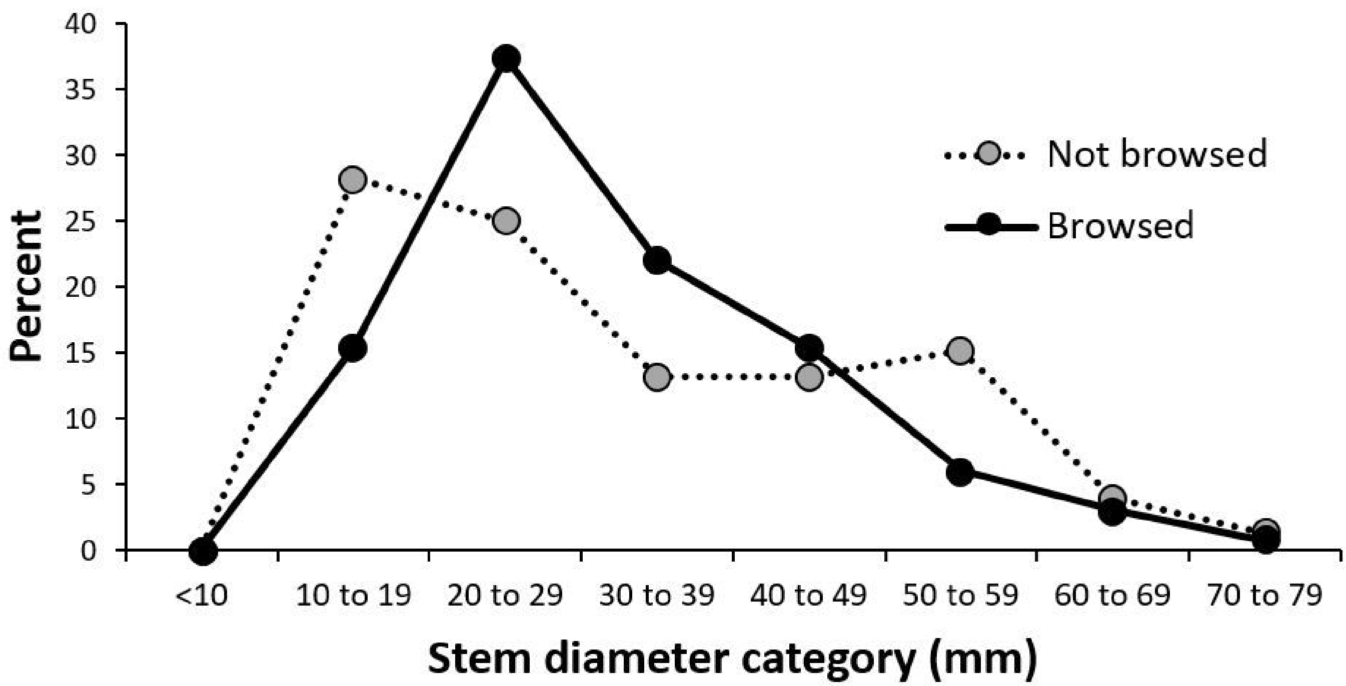

Figure 6

Stem diameter size distributions of browsed and non-browsed common buckthorn in savanna Parcel 1 after a five browsing periods

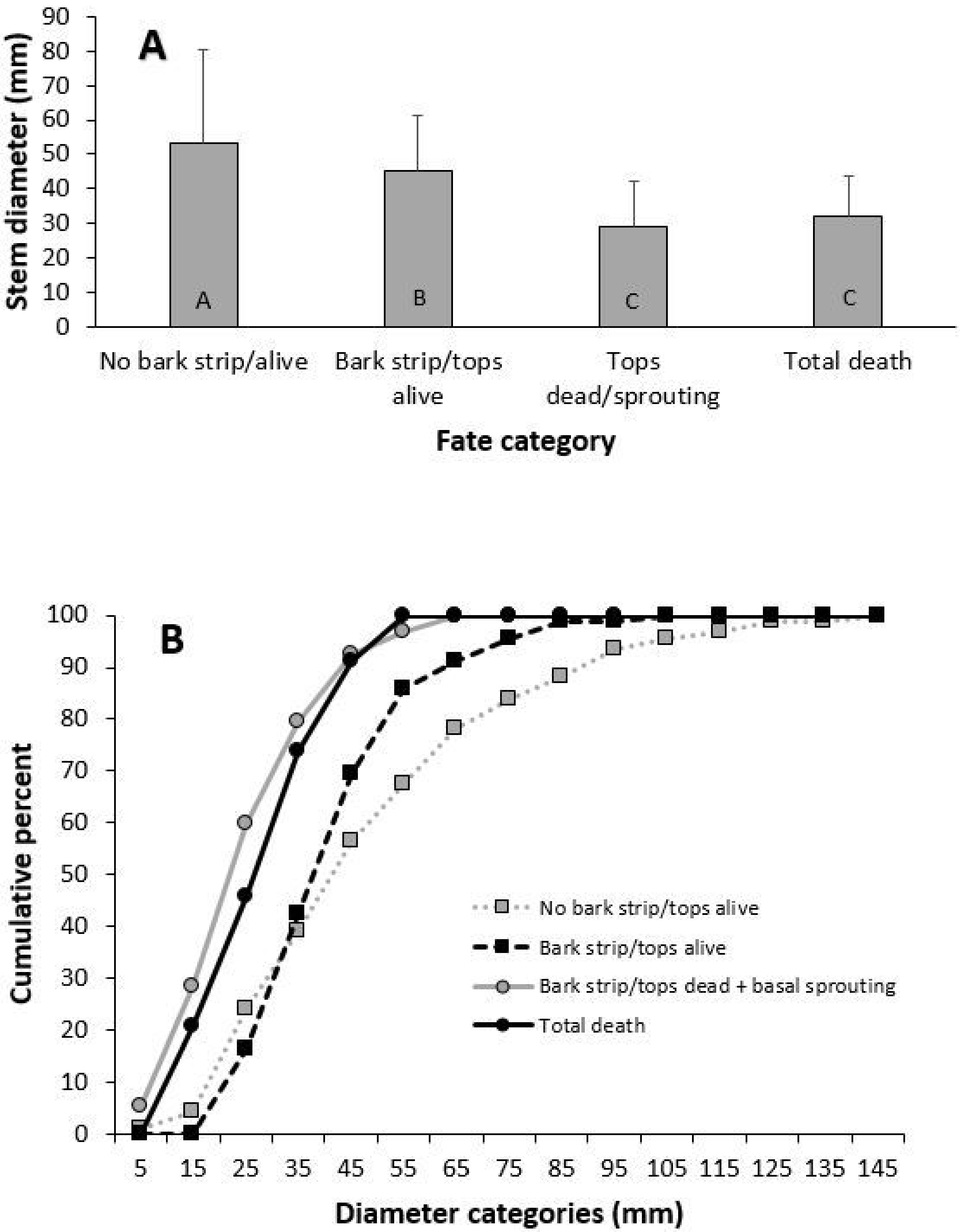

Figure 7

Stem diameters of common buckthorn grouped by fate category. A) Mean stem diameter of buckthorn by fate category. Error bars represent 1 SD. Categories not sharing the same letter are significantly different.

B) Cumulative stem size distribution of buckthorn by fate category