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Diet preferences of goats in a subtropical dry forest and implications for habitat management

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Abstract: As part of an experimental study of using controlled goat grazing to manage winter habitat of the Kirtland's warbler (*Setophaga kirtlandii*), an endangered Nearctic-neotropical migratory bird, we evaluated diet preferences of domesticated goats within early-successional subtropical dry forest in The Bahamas. We expected goats would show a low preference for two plants (*Lantana involucrata*, *Erithalis fruticosa*) important to the bird's winter diet and that occur in abundance in goat-grazed areas throughout the region. Contrary to our expectations, the plants were among a set of species, including *Acacia choriophylla*, *Passiflora* spp., and *Thrinax morrisii*, with moderate to high palatability during the mid-late dry season. Thus, strict avoidance of the two warbler food plants by goats is not a direct mechanism promoting their abundance in grazed areas. Nonetheless, grazing may still prove an economically viable means of managing existing warbler habitat by delaying succession toward a mature forest community where important food resources may be lacking.

Key words: Bahamas, coppice, *Erithalis fruticosa*, goat grazing, Kirtland's warbler, *Lantana involucrata*, resource selection.

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Introduction

Habitat conservation for threatened species often faces many social, political, and economic challenges. This is particularly true in developing nations where biological conservation must be balanced with the need of governments to facilitate the production of jobs, infrastructure, and food for growing populations (Deb *et al.* 2013; Papachristou *et al.* 2005). Identifying cost-effective and sustainable means for habitat conservation under such circumstances may require consideration of novel management approaches.

The Kirtland's warbler ("KW", *Setophaga kirtlandii*) is a migratory songbird, federally listed as endangered in the U.S.A. It breeds in young jack pine forest primarily in Michigan, U.S.A. and winters in The Bahamas archipelago (Mayfield 1992). Although successful habitat management strategies have been implemented within the KW's breeding range, there are no specific protections in place for the species or its habitat on the wintering grounds (USFWS 1985). Yet, winter habitat quality or loss can influence the reproductive success and population size of migratory species (Marra *et al.* 1998). Although there has been some past debate about the winter habitat requirements of the KW (e.g., Haney *et al.* 1998; Mayfield 1992), recent studies on the island of Eleuthera have shown the bird utilizes recently disturbed subtropical dry forest and scrub ["dry evergreen forest", Smith & Vankat (1992); "seasonal ever-

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green forest" and "mixed evergreen-deciduous shrubland", Areces-Mallea *et al.* (1999)] where the fruits of *Lantana involucrata* L. (wild sage), *Erithalis fruticosa* L. (black torch), and *Chiococca alba* (L.) Hitchc. (West Indian snowberry) are important components of its diet (Sykes & Clench 1998; Wunderle *et al.* 2010, 2014). These vegetation communities, known both locally and in the literature as "coppice" (Coker & Shattuck 1905; Correll 1979), also provide habitat for a number of other migratory and resident birds on Bahamian islands (Currie *et al.* 2005a; Currie *et al.* 2005b; Franklin & Steadman 2013).

Urban development and other forms of permanent land conversion are currently relatively limited on Bahamian "out islands" (e.g., Eleuthera), though it is probably on the rise in some areas. Undeveloped areas of dry forest may now be extensive but typically have a history of human disturbance, principally for shifting agriculture, resulting in a mosaic of stands of different ages (Byrne 1980; Helmer *et al.* 2010; Young 1966). Despite the prevalence of successional (e.g., < 25 years old) dry forest, our surveys of variously disturbed dry forests on Eleuthera have shown only a low proportion support the fruiting shrubs of primary importance in the KW winter diet (Fleming *et al.* 2015). Thus, truly suitable habitat containing critical resources may not be particularly widespread. This warrants consideration of strategies for protecting or managing existing habitat.

Two challenges facing KW habitat conservation and management within The Bahamas include (1) a scarcity of protected land and (2) costs associated with the strategic application of disturbance that is likely required to ensure availability of early-successional dry forest with the appropriate food resources. Conservation efforts will be aided by identification of (a) natural or semi-natural public or private lands that can support multiple uses, including maintenance as bird habitat, and (b) economically viable management techniques. Wunderle *et al.* (2010) observed large numbers of KWs on some Eleuthera goat farms, where "pastures" were essentially semi-natural patches of young dry forest vegetation that included an abundance of both *L. involucrata* and *E. fruticosa*. Other authors have also noted an abundance of *L. involucrata* in (sub)tropical areas grazed by either managed or feral livestock (e.g., Francis 2004; Mitchell 1999), which suggests grazing may somehow benefit the plant. Consequently, one possible conservation strategy could involve using controlled grazing with goats to maintain suitable KW habitat in semi-natural areas where it is impractical to allow development of mature forest (e.g., utility rights-of-way). Because goat meat is a popular, but currently limited, commodity in The Bahamas, such a management strategy might provide economic benefits that enhance its cost-effectiveness.

The success of a grazing-based habitat management strategy depends, in part, on whether goats are mechanistically involved in the production or maintenance of the KW habitat occurring in grazed areas, and diet preferences could be a key mechanism. Goats are well known as selective consumers and their dietary choices may contribute to either positive or negative alterations in vegetation structure and composition (El Aich & Waterhouse 1999). On islands throughout the world, feral goats have long been charged with reducing biodiversity by preferentially feeding on and sometimes extirpating native species (Chynoweth *et al.* 2013; Coblentz 1978). Nonetheless, there is often very little published information about the actual feeding behaviors of goats on natural or semi-natural lands (Rodgers 1990). Instead, in many ecological studies, dietary preferences of grazers may be only, and possibly erroneously, inferred from post-grazing composition rather than determined directly.

We hypothesized that goats might promote KW winter habitat by avoiding *E. fruticosa* and *L. involucrata* or browsing more heavily on competitors that could eventually shade them out. However, little is actually known about the palatability of these two, or other, Bahamian dry forest species despite the prevalence of both domesticated and feral goats in the region. *E. fruticosa* has been documented as a preferred forage species of Florida key deer (Barrett & Stiling 2006), but some evidence indicates a likely unpalatability of *L. involucrata*. For example, low palatability of *L. involucrata* is supported by known toxicity of the congener *L. camara* L. (Abatan *et al.* 1996; Sharma *et al.* 2007). *L. involucrata* was also classified as one of several Bahamian dry forest plants unpalatable to goats based on acceptance or rejection in direct feeding trials conducted by Byrne (1980), who also found the cover of unpalatable species, collectively, was higher near settlements where grazing was most likely to have occurred. Similarly, Larkin *et al.* (2012) suggested low palatability of *L. involucrata* contributed to the longer persistence of its high cover in cleared-and-goat-grazed areas on Eleuthera compared to areas that were cleared-only or burned.

While the studies by Byrne (1980) and Larkin *et al.* (2012) do suggest a mechanistic link between goat grazing and increased abundance of at least one of our KW food plants, evidence supporting the role of dietary preference is still scant. Aside from Byrne's direct feeding trials, we are unaware of any studies documenting the behavior of goats feeding freely within Bahamian dry forest. In this paper we examine the foraging behaviors and diet preferences of goats grazing in early-successional dry forest consistent with KW winter habitat. Diet preferences were determined from direct observation of goats in the field, selecting forage from typical assemblages of plants during short-term, experimental grazing trials. We also test the hypothesis that a key KW food plant (*L. involucrata*) is unpalatable to goats, potentially contributing to its abundance in areas subject to goat grazing. Understanding the dietary preferences of goats will help us better assess the processes contributing to the occurrence of KW habitat in goat grazed areas and aid the design of a goat-based habitat management strategy, if additional evidence supports the development of such (Barroso *et al.* 1995; Ebrahimi *et al.* 2010; Yayneshet *et al.* 2008). In addition, documenting goat diet preferences can aid inferences about the impact of feral goats in Bahamian dry forest or floristically similar vegetation types (Melendez-Ackerman *et al.* 2008).

Materials and methods

Study site and plot characteristics

Eleuthera is a low elevation (51 m max) subtropical island (518 km^2) in the central Bahamas (25° 15' N, 76° 20' W). The predominant natural vegetation is dry forest and scrub consisting of relatively dense stands of evergreen and semi-deciduous broadleaf trees and shrubs growing on poorly developed soils on limestone substrate (Correll 1979; Mooney 1905; Sealey 2006). The climate is characterized by an annual wet and dry season, with most rainfall occurring from May through October (Sealey 2006).

Our study was conducted in southwestern Eleuthera. Treatment plots were located within the pipeline system of an extensive fresh-water well field, where vegetation had been significantly thinned approximately 3-4 years prior to the onset of our study. Plots were largely dominated by shrub or tree species including *Acacia choriophylla* Benth. (cinnecord), *Bourreria ovata* Miers (strongback), and *Trema lamarckianum* (Roem. & Schult.) Blume (pain-in-the-back), but also had high cover of the vines *Jacquemontia havanensis* (Jacq.) Urb. and *Passiflora suberosa* L. (juniper-berry) along with an understory of grasses and herbaceous perennials. *L. involucrata* and *E. fruticosa* occurred on all plots in varying abundances. The maximum height of shrub or tree species within the well field was typically ~2 m, though plants on the margins of the field or immediately adjacent to water pipes were sometimes taller.

Experimental plots were established in early winter 2010 throughout an approximately 60 ha area. Twenty plots, each 6 m × 17 m in dimension (102 m^2 area), were established in a paired design (ten pairs). One plot from each pair was randomly selected for the goat grazing treatment, the other served as an ungrazed control for comparisons not addressed in this paper.

Plant sampling

Vegetation within all plots was measured prior to onset of grazing treatments and repeated in treatment plots following goat removal. Measures included estimates of: (1) plant species frequency; (2) surface litter cover and depth; and (3) total standing crop biomass (grams dry vegetation per 0.25 m^2). We used a point intercept sampling method to estimate plant frequency. Sampling points occurred at regular half-meter intervals along two intersecting transects running between opposing corners of the rectangular plot. At each sampling point, we recorded all live plant species intercepting the point within each of eleven vertical height classes extending upwards from ground level (six half-meter classes between 0 m and 3 m, followed by five 1 - 2 m classes for any taller vegetation). Presence and depth of litter to the nearest 0.5 cm were recorded at the same points. We also recorded the presence of species having some canopy within the plot boundary but not encountered during point intercept sampling.

We used a visual obstruction method to estimate standing crop biomass (Fleming *et al.* 2014). Visual obstruction estimates were obtained from eight 0.25 m^2 quadrats per plot and converted into biomass using a regression equation derived from calibration data obtained from areas immediately surrounding study plots. Averages of the eight biomass estimates per plot were compared pre- and post-treatment to determine biomass reduction by goats.

Goat treatments

The ten plot pairs were divided into two groups of five pairs each. Each group of plots was then subjected to a grazing treatment of either moderate intensity (Trial 1, "moderate grazing") or high intensity (Trial 2, "heavy grazing"), where intensity reflected the decrease in aboveground plant biomass following grazing treatments and resulted, primarily, from adjusting the stocking density. Treatment intensity was varied so we could examine how a moderate versus heavy grazing treatment in the mid-late dry season influenced subsequent vegetation recovery, but the longer-term effects of grazing on the vegetation are not addressed in this paper.

Treatment plots in Trial 1 were subjected to grazing by three Eleuthera-raised, adult female meat-goats between late February and late April 2011; treatment plots in Trial 2 were grazed by nine female goats between late February and late March 2012. Electric fencing was temporarily placed around the treatment plot while goats were present. During Trial 1, goats were confined to each plot for a total of ~13 days. During Trial 2, goats were confined to each plot for a total of ~6.5 days. In both trials, goats were confined to plots during daylight hours (approximately 0800 h to 1600 h in 2011 and 0700 h to 1800 h in 2012), but consistent with local practice, were removed to pens during night hours to reduce risk of predation. Water was available at all times and, while night-penned, goats were given a small supplement of harvested plant material including a variety of mostly palatable species. Because the night food supplement was comprised of the same species generally available on study plots and was not sufficient to sustain goats through the following day, we do not expect it had undue influence on the dietary preferences we observed in the early phase of grazing within each plot. However, food supplements may have influenced the rate of consumption of less palatable species remaining during the later phase of grazing on a plot.

Behavioral observations

On a daily basis throughout the treatment period, goats were observed at regularly scheduled intervals occurring, generally, between 0800 to 1200 h and 1300 to 1600 h. Observation periods were scheduled at 15 minute intervals for a 15 minute duration and were focused on a single animal (Altmann 1974). The focal goat for each observation period was selected according to either (1) a repeating sequence of three individuals, randomized daily (Trial 1); or (2) a nine-goat sequence counterbalanced for time of day and total number of observations across the trial period (Trial 2). We recorded focal goat activity as foraging (browsing or grazing), walking, standing still, or lying down (e.g.,Yayneshet *et al.* 2008). We also recorded rumination in combination with other activities. Time spent on each activity was recorded, with separate times for each resource foraged. Scheduled observations were conducted by two individuals: one observing the goat with binoculars, as necessary, to determine activity and resource foraged; the other keeping time with a stopwatch and recording all data.

From recorded observation data, we calculated: (1) "total foraging time" as the sum of time spent actively acquiring or consuming resources ("focused foraging") plus search time (walking); (2) "total resting time" as the sum of time spent standing still or lying down: and (3) the ratio of rumination time to focused foraging time, which is an indication of forage quality (Lofgreen *et al.* 1957). We used linear regression analyses to examine changes in these general behavior patterns through time within plots, where time was quantified as the number of "goat-days" (number of goats per plot times treatment day number) to account for more rapid food reduction with higher stocking density.

Diet preferences

We evaluated goats' relative preferences among the 17 most common species, genera, or growth forms (i.e., food resources) within our study plots by comparing the proportional use of each resource with its proportional availability. Common species or genera were limited, with one exception, to those occurring on 80 percent of plots within each trial and with a median relative frequency of 1 percent or higher. The exception was the inclusion of "snowberry" (*Chiococca alba* or *C. parvifolia* Wullschl. ex Griseb., combined), which occurred on all plots but with a relative frequency of less than 1 percent. It was included in analyses because of its importance in the KW's diet (Wunderle *et al.* 2010). Common growth forms included (1) grasses (~8 species combined; see Appendix Table 1) and (2) a subset of mostly herbaceous plants (on our plots) we expected to be perceived similarly by goats (~18 species combined; Appendix Table 1).

To quantitatively compare preferences among food resources we used two procedures chosen for different desirable properties: (1) the chi-square goodness-of-fit test with Bailey simultaneous 95 % confidence intervals (Cherry 1996; Neu *et al.* 1974), performed with RSW software (Leban 1999); and (2) Jonhson's (1980) resource ranking procedure with Waller-Duncan simultaneous comparisons, performed with the program PREFER (Pankratz & Schwartz 1994). The chi-square tests whether use is proportional to availability among the full set of resources. Bailey confidence intervals then allow classification of each resource as "preferred" or "avoided" based on whether the proportional availability of the resource is below or above the confidence limits constructed for proportional resource use. Johnson's procedure relies on the average difference between the rank order of an animal's use of a resource and the resource's rank of availability in the environment, testing the null hypothesis that all differences are equal to zero (i.e., use is equal to availability for all resources). The differences in ranks (hereafter "preference scores") also provide a relative measure of preference among resources when ordered from smallest to largest (most preferred to least preferred). The Waller-Duncan comparison procedure tests for statistically significant differences in preference scores among all resource pairs. Unlike the Bailey confidence interval method, Johnson's procedure does not label individual resources as preferred or avoided but allows groups of resources to be ordered by relative preference. One of the strengths of Johnson's rank-based procedure over the chi-square test and other preference indices is a low sensitivity to instances where availability of resources is imperfectly measured (Alldredge *et al.* 1998; Johnson 1980).

For the evaluation of preference, only resource use within the first nine goat-days was considered (days 1-3 in Trial 1 and day 1 in Trial 2). We expected observations beyond this point would be less useful in distinguishing preferred versus avoided resources, as our confined goats would eventually be forced to forage on less palatable species. Resource use was calculated, using only data from scheduled observation periods, as the percent of focused foraging time spent foraging on a specific resource. We used percent relative frequency, derived from point intercept sampling, as a measure of the availability of each resource within a plot. Percent relative frequency was calculated as the total number of times a particular resource was encountered across all points and height classes, divided by the total number of encounters within a plot. For the chi-square test and Bailey intervals, resource use was calculated separately for each goat across all plots, and resource availability was pooled across plots within trials. For Johnson's method, use and availability were calculated separately for each goat and plot.

In preliminary analyses using chi-square contingency tests, we found neither the observed percent use of common resources nor the observed percent relative frequencies within trials differed significantly from the percents expected based on their overall distributions across trials. Consequently, differences between trials in resource preference were not expected.

Results

Throughout the entire treatment period and across trials, consumption of 82 percent of species present among plots was recorded during scheduled observation periods (88 of 107 species; Appendix Table 1). Foraging on most of the remaining 18 percent of species was noted either through direct observation outside scheduled periods or through the post-treatment condition or absence of plants. Among the 88 species with recorded consumption, 46 percent (49 species) were typically consumed on the first day goats were present in a plot, though such consumption may have represented only a sampling of the plant rather than major resource use (see "Mode of 1st day consumed" and "Median % forage time on Day 1" in Appendix Table 1; however, the 46 percent here includes only instances where a single mode exists with data pooled across trials). This early consumption of a high proportion of available species indicates goats thoroughly investigated each new environment, so analysis of diet preferences during the early treatment period was not biased by goats not yet encountering all species.

Diet preferences

Within the first nine goat-days, both the chi-square goodness-of-fit test (χ^2 = 704.48, P < 0.001) and Johnson's rank-based procedure ($F_{17,41}$ = 37.44, P < 0.001) indicated the 17 most common food resources (plus all other species combined as an 18th resource) were not simply used in accordance with their availability. Four species were classified as preferred by Bailey intervals (*Acacia choriophylla*, *Passiflora* spp., *Thrinax morrisii* H. Wendl., and *Jacquemontia havanensis*), while Johnson's preference score rankings for

Table 1. Diet preferences of goats based on Johnson's difference in ranks and Bailey simultaneous confidence intervals using foraging data from goats in 102 m^2 plots on Eleuthera, The Bahamas. Analyses included the 17 most common species, genera, or growth forms within study plots, plus an additional resource group composed of all other species combined. See Appendix Table 1 for individual species included with genus, grass, and herb groups. Nomenclature follows Correll & Correll (1996).

Johnson's difference in ranks			Bailey simultaneous confidence intervals			
Resource	Preference score	Preference rank	Use lower bound	Use upper bound	Proportion available	Preference type
Chiococca spp.	-2.80	1	0.002	0.018	0.009	
Acacia choriophylla	-2.63	2	0.130	0.194	0.056	Prefer
Passiflora spp.	-2.53	3	0.057	0.105	0.048	Prefer
Erithalis fruticosa	-2.33	4	0.015	0.044	0.019	
Lantana involucrata	-2.27	5	0.041	0.082	0.045	
Thrinax morrisii	-1.73	6	0.038	0.079	0.024	Prefer
Herbaceous spp.	-1.61	7	0.004	0.024	0.022	
Pithecellobium keyense	-1.22	8	0.040	0.081	0.040	
Smilax havanensis	-1.21	9	0.000	0.010	0.018	Avoid
Tournefortia volubilis	-0.78	10	0.003	0.021	0.017	
Jacquemontia havanensis	-0.62	11	0.137	0.202	0.100	Prefer
Eugenia axillaris	-0.39	12	0.002	0.006	0.014	Avoid
All other spp.	1.47	13	0.160	0.229	0.161	
Nectandra coriacea	2.29	14	0.001	0.016	0.040	Avoid
Grass spp.	2.80	15	0.120	0.183	0.188	Avoid
Psychotria spp.	3.00	16	0.000	0.012	0.036	Avoid
Trema lamarckianum	3.36	17	0.000	0.010	0.073	Avoid
Bourreria ovata	7.20	18	0.000	0.010	0.091	Avoid

those four species ranged from second through eleventh (Table 1). This suggests some inconsistency between the methods, but Waller-Duncan comparisons indicated there was no statistically significant difference among Johnson's preference scores for the top three of the four species categorized as preferred (Fig. 1). *Acacia choriophylla*, which was also categorized as preferred forage by Byrne (1980), was the top-ranked preferred species. Across all species in our study, it also had the highest average proportional forage time on the first treatment day when goats were introduced to each plot (see "Median % forage time on Day 1" in Appendix Table 1).

Our plants of main interest (*L. involucrata*, *E. fruticosa*, and *Chiococca* spp.), were not categorized as either preferred or avoided by Bailey intervals, but had high ranking preference scores that were not statistically differentiated from the top three preferred species (Table 1; Fig. 1). *L. involucrata*, and *Chiococca alba* also had above-average proportional forage times for the first treatment day in both Trials, though *E. fruticosa* did not in Trial 1 (see "Median % forage time on Day 1" in Appendix Table 1).

The biggest ambiguity arising from comparison of the two methods involves preference for *Jacquemontia havanensis*. Although categorized as preferred by Bailey intervals, it had a mid-ranking preference score that was not statistically distinguished from two avoided species (*Smilax havanensis* Jacq. and *Eugenia axillaris* (Sw.) Willd.). *J. havanensis* was a relatively abundant vine on all plots, often blanketing mid-sized shrubs, and had relatively high average proportional consumption on the first treatment day as well as throughout each Trial (Appendix Table 1).

Qualification of less-preferred resources showed good consistency between the two methods. Six of the seven lowest ranked resources by Johnson's method, which included grasses as well as species of shrubs and subshrubs (e.g., *Psychotria* spp.),

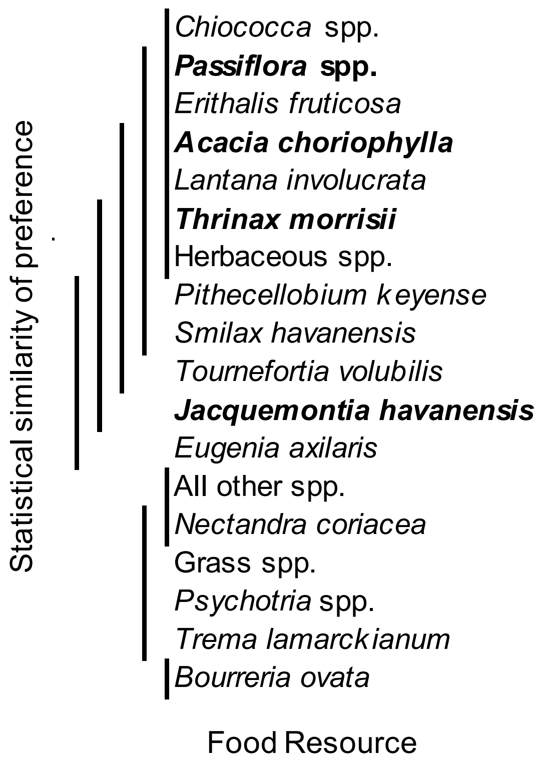

Fig. 1. Relative preferences among common plants (food resources) consumed by goats temporarily confined in 102 m^2 treatment plots on Eleuthera, The Bahamas. Relative preferences are based on Johnson's (1980) ranking method and Waller-Duncan comparisons. Preference scores for items covered by the same line on the left are not significantly different. Groups of items are effectively ordered from most preferred at the top to least preferred at the bottom based on preference scores of group members. Items in bold type were categorized as "Preferred" by Bailey confidence intervals (see Table 1).

were classed as avoided by Bailey intervals (Table 1). The lowest-ranked species, *Bourreria ovata* (strongback), was significantly less palatable than all other resources (Fig. 1) and was also categorized as unpalatable by Byrne (1980). Although *B. ovata* was typically consumed on the first day of treatment, the average proportional foraging time on Day 1 was only near the average for all species present in the study (Appendix Table 1).

General foraging behavior throughout treatment period

Beyond the first nine goat-days used for evaluation of dietary preferences, qualitative differences in general foraging behavior were apparent between trials. Goats in Trial 1 spent less time foraging and more time resting than goats in Trial 2 (Fig. 2), as well as more time ruminating (40 % vs 17 %). During Trial 1, total foraging time decreased and resting increased by approximately 1 percent per goat-day, while observed trends through time for both behaviors in Trial 2 were not statistically significant (Fig. 2). The ratio of rumination to focused foraging time also increased significantly, though gradually, through Trial 1 suggesting a reduction in forage quality over time that should be expected in a confined area (Fig. 2). In Trial 2, however, the ratio showed no significant trend through time, perhaps because forage quality was rapidly depleted under the higher stocking density. In both trials, the percent of focused foraging time spent consuming ground-layer components (*e.g.*, plant litter and roots) increased at a similar rate through the grazing period, reaching an average of 25 - 30 percent by the end of each trial (Fig. 2).

Total vegetation reduction at the end of the treatment period was higher in Trial 2, despite the longer treatment period at lower goat density in Trial 1. Plant biomass was reduced by an estimated average of 54 percent (range = 43 - 74 %) in Trial 1 compared to 81 percent (range = 69 - 88 %) in Trial 2. In both trials, median litter depth and cover were low prior to treatment onset (median depth ranged from 0.0 - 1.0 cm across all plots; litter cover averaged 37 % in Trial 1 and 47 % in Trial 2), and changes in litter depth or cover following treatment were not detected despite the relatively high levels of ground foraging near the end of the treatment period.

Discussion

The dietary preferences of goats in early-successional Bahamian dry forest indicated by our quantitative analyses generally matched the qualitative impressions we formed while observing goats in our experimental plots. However, they did not match our original hypotheses with respect to palatability of plant species important in the winter habitat of the Kirtland's warbler. Despite some evidence to the contrary, at least for *L. involucrata*, all three species appeared to have at least moderate, if not high, palatability relative to the array of plants available during the mid-late dry season. Although goats were confined to relatively small areas in our study, it is unlikely this substantially influenced our preference analyses since the analyses only utilized data from

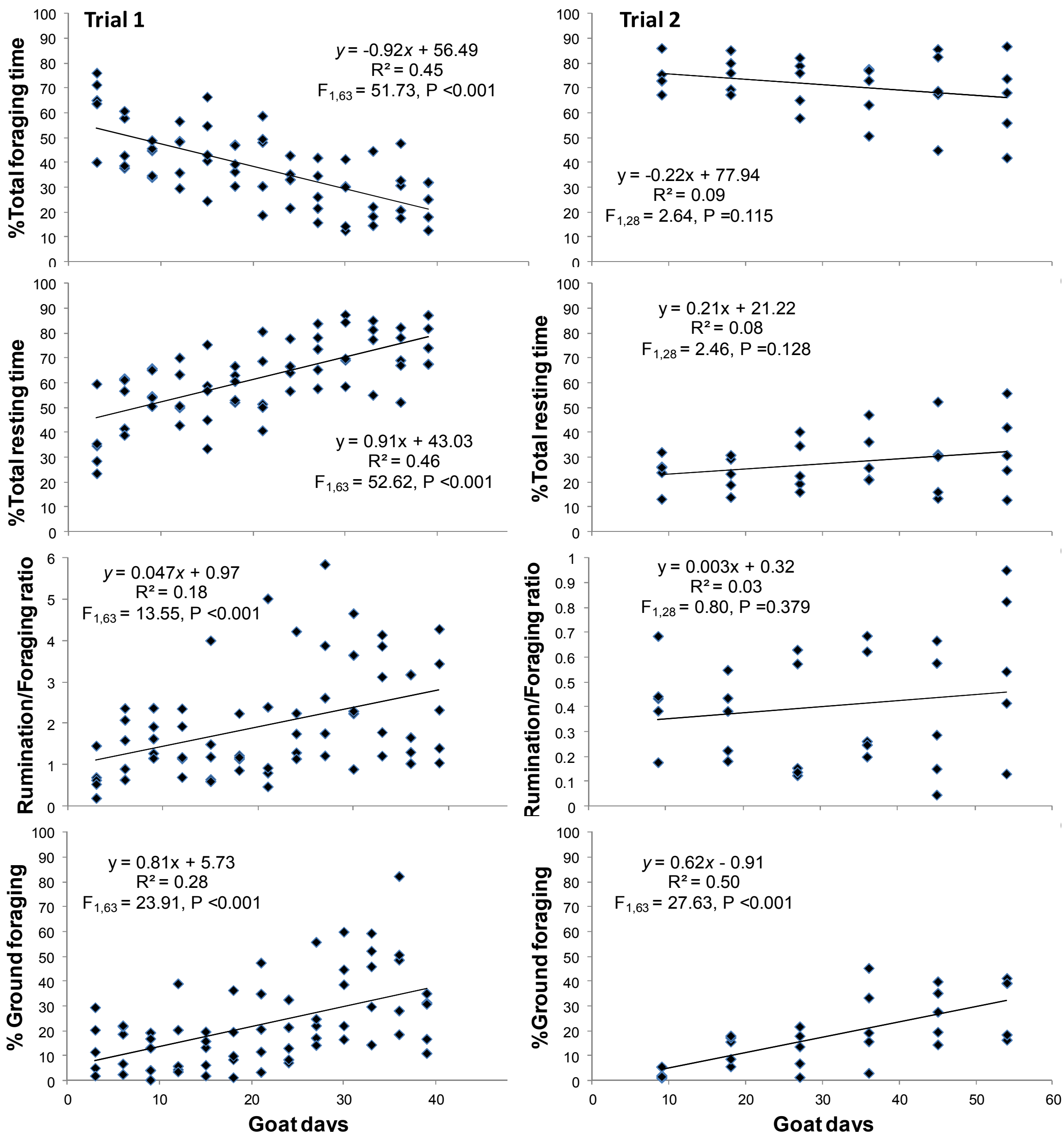

Fig. 2. Goat activities through time (in "goat-days") during two grazing trials within 102 m² treatment plots. Trial 1 (left panels) involved three female goats monitored for 13 days on each of five plots; Trial 2 (right panels) involved nine female goats monitored for 6.5 days on each of five plots. Activities are quantified as the total time spent per activity summed across goats and scheduled observation periods within each treatment day per plot. Foraging time (searching for or actively consuming food) and resting time (standing still or lying down) are expressed as percents of the total scheduled observation time. Ground foraging is expressed as a percent of the total time spent actively consuming food items. Goat-days are a function of treatment day number and stocking rates. Linear regression equations and other statistical details are shown for each relationship.

the very early stage of confinement before the depletion of preferred resources. In addition, goats were frequently observed foraging heavily on *L. involucrata*, and other preferred species, within minutes of being released into a new plot, when confinement effects should have been at a minimum.

Dietary choices by ruminants are based on a complex array of factors and could, therefore, vary under conditions differing from those in our study

(Baumont *et al.* 2000; Papachristou *et al.* 2005). Nonetheless, our results suggests prevalence of *L. involucrata* or *E. fruticosa* in areas subjected to either managed or feral goat browsing is not a direct result of strict avoidance of the plants by goats. Instead, it is possible these shrubs are more resilient to the disturbance than co-occurring species due to faster re-growth, earlier fruiting, or higher seedling recruitment in the post-grazing environment. We will investigate plant responses subsequent to grazing on our study plots in a separate manuscript. However, Francis (2004) characterized *L. involucrata* as a disturbance dependent species and *E. fruticosa* as one that benefits from reduced competition, while we have found post-disturbance survival and seedling germination of both species is enhanced in higher light environments (Fleming *et al.* 2015).

Despite a general classification of goats as browsers rather than grazers, we were still somewhat surprised by the low preference for grasses in our study. We expected they might fall into a neutral, if not preferred, category for three reasons: (1) Larkin *et al.* (2012) found very low cover of herbs, which included grasses, in goat-grazed Bahamian dry forest; (2) local goat farmers suggested to us that grasses were often a preferred resource; and (3) we frequently observed the goats consuming grasses in our plots. It is possible their very low preference ranking in our study arose from the mixed nature of the growth form-based group (see Appendix Table 1), which could include both moderately and less palatable species. However, the low preference for grass might also be a seasonal circumstance. Studies have reported lower grass consumption by ruminants during the dry compared to the wet or active growing season (Kronberg & Malechek 1997; Papachristou & Nastis 1993; Yayneshet *et al.* 2008), and our grazing trials occurred during the dry season. In addition, two of the most common grasses on our plots (*Andropogon virgincus* L. and *Paspalum blodgettii* Chapm.) are warm-season grasses known for seasonal declines in digestibility and forage quality (Blount *et al.* 2001; Leithead *et al.* 1971). Regardless of their palatability, any extent to which goats do reduce grass cover could prove beneficial to KW shrub recruitment by increasing light at ground level.

Implications for land management

The moderate to substantial reduction in plant biomass achieved by confining goats to a limited area indicates managed goat grazing may be an effective means of maintaining young dry forest stands in an early-successional state. We will evaluate whether such treatment actually maintains suitable KW winter habitat in future analyses of longer-term post-treatment data collected from our study plots. Although the goats in our study did not demonstrate an avoidance of the primary KW fruit plants, their low preference for species such as *Trema lamarckianum* and *Psychotria* spp. could prove beneficial to KW winter habitat management since fruits of these plants are consumed in lower quantities by KWs (Wunderle *et al.* 2010).

If we find goat grazing does maintain suitable KW habitat, additional investigation will still be needed to determine the most effective grazing regimes (*i.e.*, stocking rates, season, frequency) suiting multiple purposes. Effectiveness will need to consider not only the quality of bird habitat, but also how well any other land management goals are achieved and how the regime affects goat production. For example, we are interested in the potential for using goats to manage vegetation on utility rights-of-way (ROWs). It covers hundreds of miles across the islands and require periodic clearing, but still often support stands of early-successional dry forest including the primary KW fruit shrubs. It is possible goats could be a cost effective means to achieve an acceptable level of periodic vegetation thinning on ROWs, which could increase land availability for goat production. However, utility companies might desire a more intense grazing treatment than typically used in a farmer's pasture and this could, in turn, affect habitat quality and goat production.

Different patterns in the general foraging behaviors of goats in our two trials clearly show that stocking-rate has a strong influence on animals' willingness to consume less-preferred or lower quality forage, particularly when being partially supplemented. This density-dependent effect has implications for both goat-based vegetation management and factors regulating animal production under managed (or even feral) conditions. While greater vegetation reduction in shorter time periods can be achieved with higher stocking rates, a higher density of animals may also help protect individuals from significant adverse health effects where substantial vegetation reduction is needed. Low preference for some species in our study could be related to compounds that cause negative post-ingestive effects in goats [*e.g.*, calcium oxalates in *Bourreria* *ovata* (Morales 1981; Nellis 1994)]. If goat density is sufficient to limit the amount of harmful substances ingested by a single animal within some tolerance range (Barroso *et al.* 1995; Papachristou *et al.* 2005), negative impacts to animal production (or feral population growth) may be minimized. However, concentrations of harmful or unpleasant substances in plant tissues and, hence, species' palatability may also change seasonally along with availability of nutrients or other compounds that improve toxin tolerance (Papachristou *et al.* 2005). Thus, the seasonal dynamics of plant palatability and its influence on grazing capacity and animal production must also be investigated, along with plant responses to grazing in various seasons (Ebrahimi *et al.* 2010; Robles *et al.* 2009).

Conclusions

Livestock grazing and goats, in particular, are often perceived as counter-productive to biological conservation efforts due, in part, to the negative impacts of feral animals on natural landscapes. However, in countries such as the U. S., recent articles in the popular press indicate the use of small ruminants in natural lands management is on the rise (*e.g.*, Allen 2012; Foderaro 2012; Joint Fire Science Program 2009). By using a well-managed grazing regime based on a good understanding of animals' dietary preferences and nutritional needs, combined with an understanding of how the regime affects the plant community, it may be possible to achieve both biological conservation goals and broader economic goals.

More generally, our work illustrates the difficulties associated with inferring the mechanisms of disturbance effects on vegetation based on post-disturbance composition. In the case of grazing impacts, whether by domestic or feral animals, the post-grazing plant community may not always be reflective of grazers' dietary preferences. Yet knowledge of animals' feeding behaviors can help build an understanding of the mechanisms responsible for the post-grazing community as well as differences in vegetation composition through space and time. This, in turn, can aid management designs to mitigate against negative impacts or promote desired outcomes.

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Appendix Table 1. Goat foraging data for species present on 102 m² treatment plots during two grazing trials on Eleuthera, The Bahamas. Trial 1 (Feb. - Apr. 2011) involved three female goats confined to each of five plots for 13 days; Trial 2 (Feb. - Mar. 2012) involved nine female goats confined to each of five plots for 6.5 days. Foraging data were derived only from scheduled observation periods, thus "-" in a column indicates no observed foraging data were available or the species was not present on plots within a Trial. Species without foraging information may have been consumed at other times. Nomenclature follows Correll & Correll (1996). An asterisk (*) indicates multiple modes exist and the smallest value is shown.

	Trial 1					Trial 2				
Species	Plots foraged/ Plots present	Median Relative Fre-quency	Mode of 1st day consumed*	Median % forage time on Day 1	Total % forage time across trial	Plots foraged/ Plots present	Median Relative Fre-quency	Mode of 1st day consumed*	Median % forage time on Day 1	Total % forage time across trial
Species included in preference analyses as individual species or with congeners										
Arecaceae (Palmae)										
Thrinax morrisii	4/4	1.45	1*	1.69	4.08	4/4	3.17	1	6.43	3.62
Boraginaceae										
Bourreria ovata	4/5	2.84	1	0.32	0.12	5/5	8.78	1	0.34	5.32
Tournefortia volubilis	4/5	1.85	1*	0.37	0.30	5/5	1.30	1	0.71	0.95
Convolvulaceae										
Jacquemontia havanensis	5/5	14.01	1	21.29	15.38	5/5	8.65	1	10.49	8.57
Fabaceae (Leguminosae)										
Acacia choriophylla	5/5	1.90	1	27.08	12.94	5/5	8.76	1	15.19	13.93
Pithecellobium keyense	5/5	1.90	1	0.90	2.63	5/5	4.35	1	10.77	7.89
Lauraceae										
Nectandra coriacea	4/4	1.71	1*	0.33	1.20	5/5	3.04	1	0.74	3.72
Myrtaceae										
Eugenia axilaris	2/5	1.04	1	0.36	0.05	4/5	1.51	4	0.08	1.57
Passifloraceae										
Passiflora cupraea	0/0	-	-	-	-	1/1	0.43	1	0.59	0.14
Passiflora suberosa	5/5	2.59	1	11.68	4.20	5/5	3.24	1	7.78	3.36
Rubiaceae										
Chiococca alba	5/5	0.47	1	1.41	0.30	4/5	0.37	1	0.65	0.15
Chiococca parvifolia	3/3	1.85	6	0.00	0.42	1/1	0.25	1	0.09	0.003
Erithalis fruticosa	5/5	0.95	1	0.16	3.59	5/5	1.30	1	1.10	6.03
Psychotria ligustrifolia	5/5	5.18	1*	1.05	0.52	5/5	2.56	1	0.49	0.63

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Appendix Table 1. Continued.

Species	Trial 1 Plots foraged/ Plots present	Trial 1 Median Relative Fre-quency	Trial 1 Mode of 1st day consumed*	Trial 1 Median % forage time on Day 1	Trial 1 Total % forage time across trial	Trial 2 Plots foraged/ Plots present	Trial 2 Median Relative Fre-quency	Trial 2 Mode of 1st day consumed*	Trial 2 Median % forage time on Day 1	Trial 2 Total % forage time across trial
Psychotria nervosa	0/0	-	-	-	-	0/1	0.18	-	-	-
Smilacaceae										
Smilax havanensis	5/5	2.55	1	0.46	1.52	5/5	0.27	1	0.18	0.71
Ulmaceae										
Trema lamarckianum	3/4	3.56	1	0.27	0.33	5/5	4.53	1	0.32	0.63
Verbenaceae										
Lantana involucrata	5/5	5.73	1	1.96	3.96	5/5	1.84	1	3.14	2.57
Species included in analyses with "Grass spp."										
Cyperaceae										
Scleria lithosperma	5/5	4.92	1	4.18	6.60	5/5	2.52	1	3.94	1.71
Poaceae (Graminae)										
Andropogon virginicus	5/5	1.04	1*	0.40	0.18	3/4	0.22	1	1.70	0.60
Aristida adscensionis	1/1	18.65	2	0.00	0.09	0/0	-	-	-	-
Aristida ternipes	1/1	7.01	4	0.00	0.06	0/0	-	-	-	-
Eustachys petraea	0/0	-	-	-	-	1/1	0.87	1	6.38	0.19
Paspalum blodgettii	5/5	6.77	1	0.92	4.58	5/5	11.70	1	5.56	2.47
Rhynchelytrum repens	0/0	-	-	-	-	0/1	0.18	-	-	-
Schizachyrium gracile	2/2	1.20	4*	0.00	0.03	1/2	0.62	1	0.40	0.02
Species included in analyses with "Herbaceous spp."										
Asteraceae										
Eupatorium odoratum	0/1	0.47	-	-	-	0/0	-	-	-	-
Pluchea symphytifolia	1/3	0.31	2	0.00	< 0.01	0/2	0.34	-	-	-
Fabaceae (Leguminosea)										
Crotalaria pumila	0/2	0.28	-	-	-	0/0	-	-	-	-

Contd...

Appendix Table 1. Continued.

Species	Trial 1					Trial 2				
	Plots foraged/ Plots present	Median Relative Fre- quency	Mode of 1st day consumed*	Median % forage time on Day 1	Total % forage time across trial	Plots foraged/ Plots present	Median Relative Fre- quency	Mode of 1st day consumed*	Median % forage time on Day 1	Total % forage time across trial
Desmodium incanum	1/1	0.47	7	0.00	0.04	1/4	0.22	1	0.14	0.005
Stylosanthes hamata	0/1	0.32	-	-	-	1/2	0.20	1	0.40	0.01
Loganiaceae										
Spigelia anthelmia	0/0	-	-	-	-	0/1	0.18	-	-	-
Malvaceae										
Sida procumbens	0/1	0.32	-	-	-	0/2	0.20	-	-	-
Rubiaceae										
Borreria laevis	0/0	-	-	-	-	0/1	0.73	-	-	-
Galium hispidulum	3/3	0.31	1	0.81	0.07	0/1	0.25	-	-	-
Scrophulariaceae										
Stemodia maritima	0/1	0.32	-	-	-	1/1	0.23	6	0.00	0.10
Solanaceae										
Solanum erianthum	1/3	0.27	1	0.45	0.13	0/3	0.22	-	-	-
Sterculiaceae										
Melochia tomentosa	1/3	0.47	1	0.43	0.08	4/4	0.26	1	0.11	0.19
Waltheria bahamensis	0/1	0.26	-	-	-	0/1	0.23	-	-	-
Waltheria indica	5/5	2.07	1	1.93	0.59	4/5	0.87	1	0.33	0.29
Tiliaceae										
Corchorus hirsutus	1/3	0.64	1	0.88	0.06	0/2	0.24	-	-	-
Corchorus siliquosus	3/4	0.29	1	0.29	0.09	0/2	0.25	-	-	-
Turneraceae										
Turnera ulmifolia	3/4	0.31	1*	0.39	0.09	2/5	0.43	1	0.11	0.02
Verbenaceae										
Stachytarpheta jamaicensis	2/4	0.26	1*	0.40	0.02	1/2	0.20	1	0.65	0.03

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Appendix Table 1. Continued.

Species	Trial 1					Trial 2				
	Plots foraged/ Plots present	Median Relative Fre-quency	Mode of 1st day consumed*	Median % forage time on Day 1	Total % forage time across trial	Plots foraged/ Plots present	Median Relative Fre-quency	Mode of 1st day consumed*	Median % forage time on Day 1	Total % forage time across trial
Species included in analyses with "All other spp."										
Acanthaceae										
Oplonia spinosa	2/3	0.32	1	1.10	0.89	2/2	1.53	1*	1.38	2.16
Anacardiaceae										
Metopium toxiferum	0/5	1.23	-	-	-	5/5	0.25	2*	0.00	0.27
Apocynaceae										
Angadenia sagraei	1/3	0.53	2	0.00	0.03	1/2	0.25	1	0.44	0.01
Neobracea bahamensis	2/3	0.31	5*	0.00	0.03	1/4	0.24	6	0.00	0.004
Arecaceae (Palmae)										
Pseudophoenix sargentii	0/0	-	-	-	-	1/2	0.26	1	5.33	0.21
Asteraceae										
Baccharis dioica	1/2	0.68	4	0.00	0.21	3/3	0.25	1	0.98	0.45
Eupatorium villosum	1/1	0.53	10	0.00	< 0.01	1/4	0.23	1	0.11	0.09
Bignoniaceae										
Tabebuia bahamensis	5/5	0.27	1*	0.39	0.19	2/4	0.25	1*	0.64	0.11
Boraginaceae										
Cordia bahamensis	2/3	0.32	2*	0.00	0.15	1/2	0.39	3	0.00	0.02
Burseraceae										
Bursera simaruba	1/4	0.47	1	0.66	0.02	5/5	0.23	1	0.44	1.70
Celastraceae										
Crossopetalum rhacoma	1/3	0.31	4	0.00	<0.01	0/1	0.27	-	-	-
Maytenus buxifolia	0/2	0.28	-	-	-	0/0	-	-	-	-
Ebenaceae										
Diospyros crassinervis	0/1	0.31	-	-	-	1/1	0.23	6	0.00	0.002
Erythoxylaceae										
Erythroxylum rotundifolium	3/3	0.27	1*	0.18	0.15	3/3	0.54	2	2.01	0.39

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Appendix Table 1. Continued.

Species	Trial 1					Trial 2				
	Plots foraged/ Plots present	Median Relative Fre-quency	Mode of 1st day consumed*	Median % forage time on Day 1	Total % forage time across trial	Plots foraged/ Plots present	Median Relative Fre-quency	Mode of 1st day consumed*	Median % forage time on Day 1	Total % forage time across trial
Euphorbiaceae										
Ateramnus lucidus	2/3	0.32	1	0.87	0.37	3/3	0.73	2	0.88	0.73
Bonania cubana	0/1	0.31	-	-	-	0/0	-	-	-	-
Croton eluteria	1/1	0.31	1	0.24	0.02	1/1	0.25	1	0.13	0.01
Croton lucidus	1/1	1.85	12	0.00	< 0.01	1/1	4.03	4	0.00	0.04
Drypetes lateriflora	0/0	-	-	-	-	0/1	0.23	-	-	-
Euphorbia blodgettii	0/0	-	-	-	-	0/1	0.37	-	-	-
Phyllanthus epiphyllanthus	0/2	0.43	-	-	-	1/1	0.22	3	0.00	0.05
Fabaceae (Leguminosea)										
Cassia chapmanii	0/0	-	-	-	-	0/1	0.23	-	-	-
Galactia rudolphioides	3/3	1.27	1*	1.03	0.09	2/2	0.26	1*	0.14	0.05
Galactia spiciformis	2/2	0.25	1*	2.16	0.08	2/3	0.43	1*	0.44	0.02
Leucaena leucocephala	1/1	0.47	1	1.10	0.17	0/0	-	-	-	-
Lysiloma latisiliquum	0/0	-	-	-	-	1/1	0.54	1	1.12	0.14
Lysiloma sabicu	0/1	0.26	-	-	-	0/0	-	-	-	-
Piscidia piscipula	0/2	0.27	-	-	-	2/2	0.34	2*	0.00	0.02
Malpighiaceae										
Malpighia polytricha	0/2	0.29	-	-	-	0/0	-	-	-	-
Triopteris jamaicensis	0/2	0.39	-	-	-	1/1	0.46	2	0.00	0.08
Meliaceae										
Swietenia mahagoni	0/0	-	-	-	-	2/2	1.17	1*	0.17	0.08
Myrtaceae										
Eugenia foetida	2/3	0.31	1*	0.39	0.02	0/1	0.27	-	-	-

Contd...

Appendix Table 1. Continued.

Species	Trial 1					Trial 2				
	Plots foraged/ Plots present	Median Relative Fre- quency	Mode of 1st day consumed*	Median % forage time on Day 1	Total % forage time across trial	Plots foraged/ Plots present	Median Relative Fre- quency	Mode of 1st day consumed*	Median % forage time on Day 1	Total % forage time across trial
Myrcianthes fragrans	0/2	1.22	-	-	-	1/3	0.25	1	0.19	0.02
Nytaginaceae										
Guapira discolor	4/5	0.31	1*	0.24	0.23	4/5	0.27	1*	0.31	0.04
Guapira obtusata	5/5	0.32	1*	1.14	1.06	4/4	0.71	1	3.69	0.90
Orchidaceae										
Oeceoclades maculata	4/4	0.29	1	4.17	1.37	3/4	0.26	1	0.19	0.22
Poaceae (Graminae)										
Lasiacis divaricata	2/3	0.64	1	2.85	0.41	2/5	0.25	1*	0.32	0.35
Polygonaceae										
Coccoloba diversifolia	5/5	0.32	2	0.00	0.34	5/5	0.54	1	0.12	1.14
Coccoloba tenuifolia	0/0	-	-	-	-	0/1	0.92	-	-	-
Polypodiaceae										
Pteridium aquilinum var. caudatum	1/1	0.26	5	0.00	< 0.01	0/0	-	-	-	-
Rhamnaceae										
Krugiodendron ferreum	0/3	0.27	-	-	-	1/2	0.26	6	0.00	0.01
Reynosia septentrionalis	5/5	0.62	1	1.80	5.06	3/3	0.50	1	0.47	0.39
Rubiaceae										
Exostema caribaeum	2/3	0.64	2*	0.00	0.10	2/3	0.25	1*	0.76	0.09
Guettarda elliptica	4/5	0.32	1	0.16	0.09	2/5	0.23	1*	0.27	0.02
Guettarda krugii	0/0	-	-	-	-	1/1	0.23	2	0.00	0.02
Guettarda scabra	2/3	0.31	2*	0.00	0.06	0/1	0.25	-	-	-
Randia aculeata	4/5	0.32	1	0.22	0.15	4/5	0.25	2	0.32	0.88

Contd...

Appendix Table 1. Continued.

Species	Trial 1: Plots foraged/ Plots present	Trial 1: Median Relative Fre- quency	Trial 1: Mode of 1st day consumed*	Trial 1: Median % forage time on Day 1	Trial 1: Total % forage time across trial	Trial 2: Plots foraged/ Plots present	Trial 2: Median Relative Fre- quency	Trial 2: Mode of 1st day consumed*	Trial 2: Median % forage time on Day 1	Trial 2: Total % forage time across trial
Rutaceae										
Amyris elemifera	2/4	0.31	2*	0.00	0.07	1/4	0.24	3	0.00	0.02
Zanthoxylum coriaceum	3/4	0.29	1*	5.86	0.42	2/5	0.23	1*	0.26	0.05
Zanthoxylum fagara	0/0	-	-	-	-	0/1	0.46	-	-	-
Zanthoxylum flavum	0/2	0.27	-	-	-	0/1	0.22	-	-	-
Sapindaceae										
Exothera paniculata	3/3	0.47	3	0.89	0.09	1/4	0.26	1	0.60	0.02
Hypelate trifoliata	1/3	0.31	7	0.00	< 0.01	1/1	0.25	3	0.00	0.01
Serjania diversifolia	1/4	0.28	5	0.00	0.02	2/3	0.25	1*	0.97	0.11
Thouinia discolor	4/5	0.53	1*	0.11	0.02	3/3	0.46	1	0.16	0.01
Sapotaceae										
Bumelia salicifolia	3/5	0.32	2*	0.00	0.10	2/3	0.50	1*	0.30	0.07
Manilkara zapota	1/1	0.24	13	0.00	< 0.01	0/0	-	-	-	-
Mastichodendron foetidissimum	1/1	0.31	2	0.00	0.49	0/0	-	-	-	-
Simaroubaceae										
Alvaradoa amorphoides	0/1	0.52	-	-	-	0/0	-	-	-	-
Solanaceae										
Solanum bahamense	5/5	0.32	1	1.67	2.04	5/5	0.54	1	5.42	1.96
Sterculiaceae										
Helicteres jamaicensis	0/0	-	-	-	-	1/1	0.25	1	0.16	0.01
Helicteres semitriloba	0/0	-	-	-	-	0/1	1.01	-	-	-
Verbenaceae										
Lantana bahamensis	3/3	1.90	6	0.00	0.08	1/4	0.37	1	0.19	0.01
Grand Medians		0.35		0.36	0.16		0.27		0.33	0.14