INFLUENCE OF ECOLOGICAL PARAMETERS ON GROWTH OF BUSH TEA (*ATHRIXIA PHYLOCOIDES* DC.) IN LIMPOPO PROVINCE, SOUTH AFRICA

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Abstract. The influence of ecological factors on the growth of bush tea was studied at Haenertsburg, Witvlag, and two sites at Khalavha in the Limpopo Province of South Africa in three consecutive years viz., 2014, 2016 and 2017, respectively. In each site, a hundred meter transect divided into one square meter quadrats five meters apart was laid. In each quadrat, bush tea plants were counted manually. Plant height and stem diameter were measured and leaves were counted for each plant. Bush tea density, frequency, abundance, ground cover and species richness were also recorded. Higher bush tea density, frequency, abundance, species richness and ground cover were positively correlated with the plant height, stem diameter and number of leaves per plant within the plant community. Bush tea density, frequency and abundance had the highest influence on the number of leaves and plant height. Plant ground cover and species richness influenced plant height, stem diameter and number of leaves the most. This study provided understanding on effect of ecological parameters on growth of bush tea individuals in a plant community in order to establish large scale bush tea plantations.
Keywords: *abundance, density, frequency, ground cover, spiecies richness*

Introduction

Bush tea (*Athrixia phylocoides* DC.) is a shrub with high potential currently being utilized as a traditional medicine for cleansing blood, treating ailments such as boils, headaches, infested wounds and coughing. Biochemical profiling of bush tea has shown that it possesses significant compounds such as 5- hydroxyl - 6,7,8,3',4',5'-hexamethoxy flavon- 3- ol (Mashimbye et al., 2006; Mavundza et al., 2010), 3-0-demethyldigicitrin, 5,6,7,8,3',4'-hexamethoxyflavone and quecertin, total polyphenols (Mudau et al., 2007a,b), tannins (Mudau et al., 2007b) and total antioxidants (Mogotlane et al., 2007).

However, as a member of a plant community bush tea interacts with other plant species and the environment. These interactions determine the growth of bush tea. In areas of favourable conditions bush tea plants are likely to produce more biomass and in marginal areas growth is likely to be stifled. The intention of plant community ecologists is to understand these dynamics and the occurrence and abundance of certain species in space and time (Loreau et al., 2001; Rehfeldt et al., 2006).

For various plant species, it is known how ecological dynamics influence the growth of the plant such as in the studies of Tilman (1988), Weiner (1988) and Bardgett et al. (2005), which recorded various aspects of plant species interactions. Bush tea height, stem diameter and number of leaves per plant significantly ($p < 0.01$) increased with

average daily rainfall (39.85 mm), average relative humidity (63.83%) and average temperature (29.21°C) in Limpopo Province, South Africa (Tshikhudo et al., 2019). However, knowledge on the influence of bush tea density, bush tea frequency, bush tea abundance, species richness and ground cover on growth of bush tea has not been generated. The goal of the present study was to test whether relationships exist between density, frequency, abundance, species richness and ground cover that influence growth of bush tea.

Materials and methods

Study area, measurement of plant growth and plant community parameters

Four roadside and easily accessible areas in Haenertsburg (23°56'21"S, 29°53'27"E), Khalavha Site 1 (22°55'43"S, 30°77'37"E), Khalavha Site 2 (22°55'41"S, 30°17'20"E), and Witvlag (22°58'44"S, 29°57'07"E), all situated in the Limpopo Province of South Africa were selected for the current study (*Figure 1*). Three site visits were conducted on 14 November 2014, 12 January 2016 and on 09 January 2017.
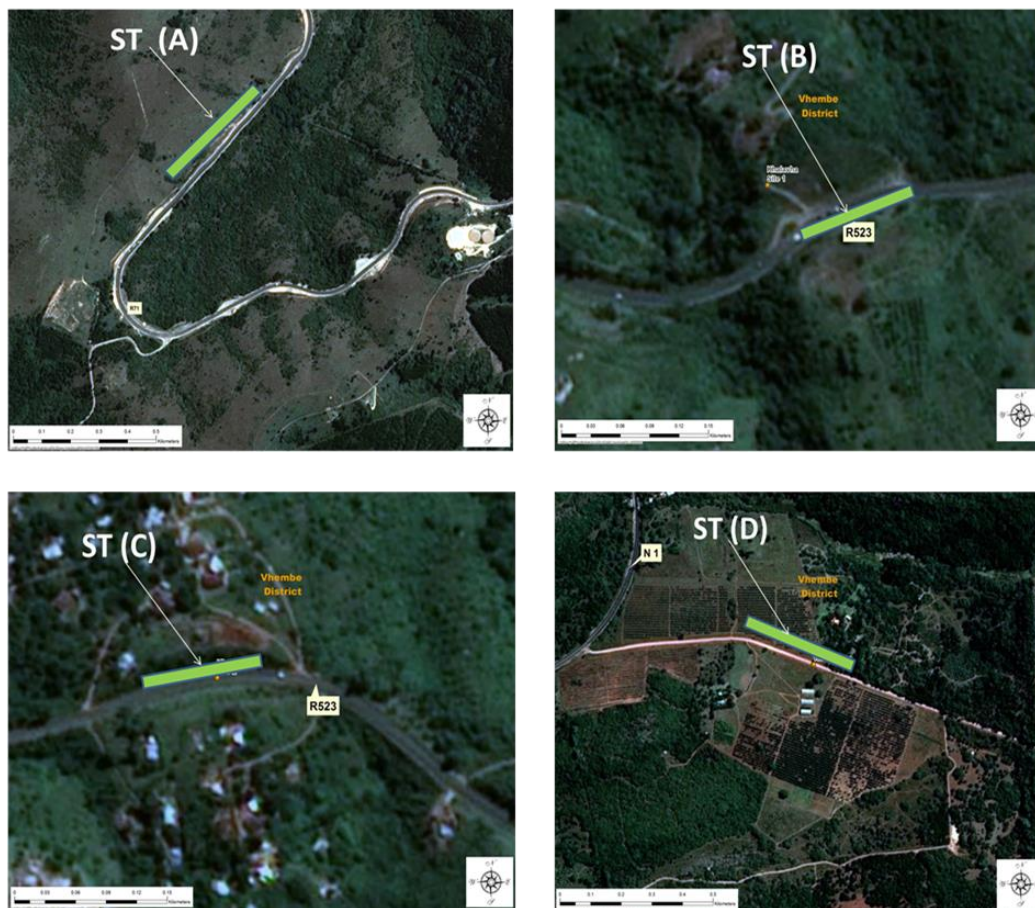

Figure 1. *Samplinglocations for bush tea (Athrixia phylicoides DC.) in the study sites (Haenertsburg (A), Khalavha Site 1 (B), Khalavha Site 2 (C) and Witvlag (D)) in Limpopo Province. A 100 metre site transect (ST) was used for sampling 1 m² quadrats at each sampling site*

In each of the four selected sites, a hundred meter transect divided into one square meter quadrats five meters (i.e 20 quadrats per transect) apart was laid. In each quadrat, bush tea plants were counted. Plant height and stem diameter were measured using tape measure and vernier caliper. The leaves were counted for each plant. Bush tea density, frequency, and abundance were calculated with reference to the methods performed by Curtis and Melntoch (1950); and Mueller-Dombois and Ellenberg (1974) as shown in *Equations 1–3*:

$$BT_{density} = \left(\frac{\text{Total number of BT in all quadrats on a transect}}{\text{Total number of quadrats studied on a transect}} \right) \quad (\text{Eq.1})$$

$$BT_{frequency} = \left(\frac{\text{Total number of BT in all quadrats on a transect}}{\text{Total number of quadrats studied on a transect}} \right) \times 100 \quad (\text{Eq.2})$$

$$BT_{abundance} = \left(\frac{\text{Total number of BT in all quadrats on a transect}}{\text{Total total number of quadrats in which BT occurred on a transect}} \right) (\text{Eq.3})$$

where, $BT_{density}$ (BT_d) refers to an expression of the numerical strength of a bush tea plant where the total number of bush tea individuals in all the quadrats is divided by the total number of quadrats studied, $BT_{frequency}$ (BT_f) is the degree of dispersion of bush tea plants in an area and usually expressed in terms of percentage occurrence, $BT_{abundance}$ (BT_a) is the number of individuals of different species in the community per unit area, and BT stands for bush tea individuals studied.

Number of each plant species was calculated in each quadrat to determine species richness. Plant ground cover (vegetation litter, plant debris and living plants) was estimated based on field observations.

Data analysis

The data on bush tea growth parameters were correlated with ecological parameters using Pearson correlations in Statistica, Version 2010 (StatSoft Inc., Tulsa, OK, USA). A plant community with high correlation coefficient with any plant growth parameter was assumed to have had the biggest influence on that particular parameter.

Results

The current study revealed that increased bush tea density, frequency, abundance, species richness and ground cover were positively correlated with the plant height, stem diameter and numbers of leaves per plant within the plant community. Bush tea density, frequency and abundance had the highest influence on the number of leaves and plant height.

Bush tea community analysis and growth parameters

In all sampling periods (three consecutive years viz., 2014, 2016 and 2017, respectively), 855 bush tea individuals were assessed for their abundance, density, frequency, ground cover they occupy and number of plant species co-existing with bush tea (*Table 1*). Plant height and stem diameter measurements, leaf counts per plant during all survey periods in all sampling sites are also appearing in *Table 1*. In terms of abundance, bush tea individuals ranged from 8.5 to 10.3 on 1 m² quadrat along 100 m transect during all sampling periods in all study sites. Density of bush tea individuals

ranged from 2.9 to 3.9 plants per quadrat with a frequency of 32.5-38.7% during all survey periods in all sampling times. Number of different plant species recorded in all areas during all survey periods ranged from 3.5-9.1 mixed with vegetation liter and debris covered about 30.2-83.2% of ground. On average, bush tea plant height ranged from 126.3 to 509.5 mm, with a stem diameter ranging from 1.3-4.7 mm, and 100.8-494 leaves per plant (*Table 1*).

Table 1. *Bush tea density, frequency and abundance values at Haenertsburg, Khalavha Site 1, Khalavha Site 2 and Witvlag during all survey periods. Plants sampled on the different sampling dates. The count of plants is for the entire 100 m transect laid during the survey in all the three survey dates growth parameters of naturally growing bush tea*

Sampling date	Parameter	Haenertsburg	Khalavha Site 1	Khalavha Site 2	Witvlag	Average
14 November 2014	n	114	23	110	48	73.7
	BT_d	2.8	1.1	5.4	2.3	2.9
	BT_f (%)	30.0	25.0	50.0	25.0	32.5
	BT_a	9.3	4.4	10.9	9.4	8.5
	SP	3.5	4.0	3.1	3.5	3.5
	PGC (%)	35.1	29.5	11.3	45.0	30.2
	Pant height (mm)	128.6	121.1	135.1	120.7	126.3
	Stem diameter (mm)	1.3	1.4	1.5	1.2	1.3
	Number of leaves per plant	136.0	84.5	97.6	85.4	100.8
15 January 2016	n	32	35	113	60	60.0
	BT_d	3.2	1.7	5.6	2.9	3.3
	BT_f (%)	30.0	35.0	55.0	30.0	37.5
	BT_a	10.6	5.0	10.1	11.8	9.3
	SP	6.4	6.3	6.8	6.6	6.5
	PGC (%)	5.7	42.7	56.5	64.6	42.3
	Pant height (mm)	256.8	416.8	468.5	410.3	388.1
	Stem diameter (mm)	2.4	3.9	3.8	3.8	3.4
	Number of leaves per plant	222.3	402.6	390.5	402.8	354.5
12 January 2017	n	82	41	113	84	80.0
	BT_d	4.0	2.0	5.7	4.2	3.9
	BT_f (%)	35.0	35.0	55.0	30.0	38.7
	BT_a	11.5	5.7	10.3	14.0	10.3
	SP	9.4	9.5	7.8	9.8	9.1
	PGC (%)	*85*	*82.8*	83.4	81.8	83.2
	Pant height (mm)	472.6	538.6	496.4	530.7	509.5
	Stem diameter (mm)	4.2	5.1	4.3	5.5	4.7
	Number of leaves per plant	464.3	521.1	467.5	523.1	494.0

BT_d = Bush tea density, BT_f = Bush tea frequency, BT_a = Bush tea abundance, SR = Species richness, PGC = Plant ground cover, n = Number of bush tea individuals present and assessed) (N=855)

Relationship between plant community and bush tea growth

Plant community parameters correlated strongly with the growth of bush tea in all sites (Haenertsburg, Witvlag, Khalavha Site 1 and Khalavha Site 2 in the Limpopo Province. Increased plant height, stem diameter and the number of leaves per plant were associated with increased ground cover, species richness, bush tea density, frequency and bush tea abundance across all the four study (*Table 2*).

Table 2. *Correlation between bush tea density, bush tea frequency, bush tea abundance, species richness and plant ground cover with the growth of bush tea at Haenertsburg (A), Khalavha Site 1 (B), Khalavha Site 2 (C) and Witvlag (D) during all survey times*

Ecological parameters	Plant height (mm)				Stem diameter (mm)				Number of leaves per plant			
	A	**B**	**C**	**D**	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**
BT_d	0.87 (p=0.000)	0.87 (p=0.000)	0.80 (p=0.000)	0.92 (p=0.000)	0.64 (p=0.000)	0.89 (p=0.000)	0.86 (p=0.000)	0.88 (p=0.000)	0.86 (p=0.000)	0.94 (p=0.000)	0.80 (p=0.000)	0.90 (p=0.000)
BT_f	0.87 (p=0.000)	0.87 (p=0.000)	0.80 (p=0.000)	0.92 (p=0.000)	0.64 (p=0.000)	0.89 (p=0.000)	0.86 (p=0.000)	0.88 (p=0.000)	0.86 (p=0.000)	0.94 (p=0.000)	0.80 (p=0.000)	0.90 (p=0.000)
BT_a	0.87 (p=0.000)	0.87 (p=0.000)	0.80 (p=0.000)	0.92 (p=0.000)	0.64 (p=0.000)	0.89 (p=0.000)	0.86 (p=0.000)	0.88 (p=0.000)	0.86 (p=0.000)	0.94 (p=0.000)	0.80 (p=0.000)	0.90 (p=0.000)
SP	0.73 (p=0.000)	0.49 (p=0.000)	0.61 (p=0.000)	0.76 (p=0.000)	0.61 (p=0.000)	0.51 (p=0.000)	0.74 (p=0.000)	0.72 (p=0.000)	0.72 (p=0.000)	0.51 (p=0.000)	0.62 (p=0.000)	0.74 (p=0.000)
PGC	0.58 (p=0.000)	0.42 (p=0.000)	0.75 (p=0.000)	0.92 (p=0.000)	0.45 (p=0.000)	0.40 (p=0.000)	0.80 (p=0.000)	0.88 (p=0.000)	0.55 (p=0.000)	0.44 (p=0.000)	0.76 (p=0.000)	0.89 (p=0.000)

Correlations between variables were assessed using Pearson rank correlation test. R^2 values are considered significant at $P \leq 0.05$. BT_d = Bush tea density, BT_f = Bush tea frequency, BT_a = Bush tea abundance, SR = Species richness, PGC = Plant ground cover

In all four study sites at Haenetsburg, Khalavha 1, Khalavha 2 and Witvlag, bush tea density, frequency and abundance positively and strongly correlated ($R^2 > 0.86$; p <0.01) with plant heights of bush tea across all the four study sites (*Table 2*). Results of the current study showed that bush tea density, density and abundance positively and strongly correlated ($R^2 > 0.81$; p <0.01) with stem diameter of bush tea in all four study sites (*Table 2*). Similarly, bush tea density, density and abundance positively and strongly correlated ($R^2 > 0.87$; p <0.01) with bush tea's number of leaves per plant across all four study sites (*Table 2*).

In the current survey of plant community analysis, species richness strongly correlated ($0.61 \leq R^2 \leq 0.68$; p <0.01) with growth of bush tea in terms of plant height in all four sites (*Table 2*). Species richness also had a strong relationship ($0.61 \leq R^2 \leq 0.68$; p <0.01) with the bush tea stem diameter across all four sites (*Table 2*).

There was a strong relationship between species richness and bush tea number of leaves per plant in all four areas ($R^2 > 0.64$; p <0.01; *Table 2*). During the current study it was evident that in sites where the species richness was high the bush tea plant outgrew other plant species within the community.

The results presented in *Table 2* indicate that there was a strong influence of plant ground cover on growth of bush tea plant in terms of bush tea plant height ($0.58 \leq R^2 \leq 0.75$; p <0.01) in all four sites. Plant ground cover also had a positive and significant relationship with bush tea stem diameter ($0.60 \leq R^2 \leq 0.75$; p <0.01; *Table 2*) across all four sites. The number of leaves per bush tea plant had a positive and significant correlation with ground cover ($0.60 \leq R^2 \leq 0.72$; p <0.01; *Table 2*) in all four selected sites.

Bush tea density, frequency and abundance had the highest influence on number of leaves and plant height. Plant ground cover and species richness influenced plant height, stem diameter and number of leaves the most (*Table 2* and *Table 3*). Ranking of the ecological factors' influence on bush tea growth parameters seems to indicate that bush tea density, bush tea frequency, and bush tea abundance ranked higher than species richness and plant ground cover in all selected study sites (*Table 3*).

Table 3. *Ranking of the level of influence of ecological factors on the plant growth parameters*

Rank	Plant height (mm)				Stem diameter (mm)				No of leaves per plant			
	A	**B**	**C**	**D**	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**
Rank 1	BT_d, BT_f, BT_a	BT_d, BT_f, BT_a	BT_d, BT_f, BT_a	BT_d, BT_f, BT_a PGC	BT_d, BT_f, BT_a	BT_d, BT_f, BT_a	BT_d, BT_f, BT_a	BT_d, BT_f, BT_a PGC	BT_d, BT_f, BT_a	BT_d, BT_f, BT_a	BT_d, BT_f, BT_a	BT_d, BT_f, BT_a
Rank 2	SR	SR	PGC	SR	SR	SR	PGC	SR	SR	SR	PGC	PGC
Rank 3	PGC	PGC	SR		PGC	PGC	SR		PGC	PGC	SR	SR

A = Haenertsburg, B = Khalavha Site 1, C = Khalavha Site 2, D = Witvlag, BT_d = Bush tea density, BT_f = Bush tea frequency, BT_a = Bush tea abundance, SR = Species richness, PGC = Plant ground cover

Discussion

Understanding the relationship between ecological parameters and growth of plant is crucial to assess species adaptation in a particular area. The current study has revealed how plant density, frequency, abundance, species richness and ground cover can influence the vegetative growth of wild bush tea (*Athrixia phylicoides*). Bush tea density, frequency, abundance, species richness and ground cover at Haenertsburg, Khalavha Site 1, Khalavha Site 2 and Witvlag in the Limpopo Province positively correlated with plant height, stem diameter and number of leaves of *A. phylicoides*. It was evident in the study sites that bush tea plant height, stem diameter and number of leaves were all higher at all study sites that had higher bush tea density, frequency, abundance, species richness and ground cover (*Table 1*).

Looking at the fact that associations of ecological factors and vegetative growth of plant are often complex, densities of individual species and the overall plant species diversity are often inversely related in natural communities and interact to affect plant populations (Bach and Hruska, 1981). Densities and individual plant weights together determine yield per unit area. Net primary production (NPP) is the rate of change in yield per unit area. Increases in biomass from growth, decreases from mortality, and tissue-nutrient concentrations provide the necessary information for evaluation of changing nutrient pools (Clark, 1990). The results of the current study may be associated with the density-plant-weight relationships and Michaelis-Menten uptake dynamics for light and below-ground resources that influence the individual plant's growth and population mortality on the timing of NPP. This may also influence the relationship between NPP and rate of individual plant weight gain, resource limitation, and below-ground resource pool size (Clark, 1990).

Plant density is an important ecological parameter that manipulates micro environment and affects growth, development and yield formation of plants (Rahman et al., 2011; Turbin et al., 2014). Plant height and number of branches per plant influence the canopy closure and therefore, they contribute to light interception by the plant. Species that are restricted in their geographic distribution tend to be scarce whereas widespread species are likely to occur at high densities (Verberk, 2011). In the current study, bush tea abundance was estimated by recording species presence in 100 m^2 transects in the study sites. The abundance and distribution of each species are limited by the combination of physical and biotic environmental variables that determines the multidimensional niche (Brown, 1984). This was probably the situation in the four study sites visited in this field study where bush tea plants were found mostly abundant in the wild along roadsides (*Table 1*).

The relationship between species richness and productivity is an example where different patterns have been found at different scales, and hence different models were used to explain variation in species richness at different scales (Waide et al., 1999; Grytnes, 2000). Increased resources available to plant may lead to greater productivity leading to greater cover and height of shrubs (Harper et al., 2018). Inter-specific competition among plant species during early stages of plant establishment can influence individual plant growth and determine subsequent development patterns of plant community (Boyden et al., 2009). Competitive interactions in young plants are positively related to photosynthetic capacity and relative growth rates that have strong positive correlations with plant traits such as specific leaf area and leaf area ratio (Boyden et al., 2009). As seen in all the study sites in the Limpopo Province, bush tea grows together with about 6 to 9 species of broad-leaved annual plants and graminoids.

Ground cover is another useful variable in soil protection and evapotranspiration estimations (Mullan and Reynolds, 2010). Percent ground cover analysis is typically used to estimate abundance of ground vegetation (Mueller-Dombois and Ellenberg, 1974; Chiarucci et al., 1999). In the current study, the percentage ground cover had a strong positive correlation with growth of bush tea plant in terms of height, stem diameter and number of leaves per plant (*Table 2*). From the study conducted by Harper et al. (2018) to determine the patterns of shrub abundance and relationships with other plant types within the forest–tundra ecotone in northern Canada, it was found that in the ecotone there were positive correlations of short and medium-tall shrubs with graminoids, forbs, and sphagnum, and negative correlations with lichens, other moss, and trees (only with trees for medium-tall shrubs) at very fine scales.

On the other hand, the tundra, shrub richness was negatively correlated with the cover of graminoids, forbs, and non-sphagnum moss, but positively correlated with lichens. The relationships between biomass and percentage cover can be used in ecosystem and carbon-cycle modelling for estimation of the aboveground biomass of plants (Naeem et al., 1994; Tilman et al., 2001; Muukkonen et al., 2006). Since bush tea is grown in open herbaceous vegetation, plant growth may be limited by the availability of below ground resources in unproductive habitats - or by the maximum growth rates of species - early phase of vegetation regeneration after disturbance in productive habitats.

He et al. (2018) determined whether shrubs facilitate or have negative effects on neighbouring herbaceous vegetation, and such effects vary with herb growth stage and with shrub orientation relative to herbs, and found that species number of herb-layer plants tended to increase from beneath the canopy to the opening, but plant density, cover and plant height decreased with distance away from shrub base. It was found that the presence of *Reaumuria soongorica* had positive effects on density, cover, and plant height, and negative on the number of herbaceous species during the entire growing season. Furthermore, Gatti et al. (2017) determined the relationship between vascular plant species richness and average forest canopy height and discovered a significant strong correlation between species richness and plant height. In agreement with findings in the current study, a strong positive correlation was found between species richness and bush tea plant height in three of the study sites (Haenertsburg (73%); Khalavha Site 2 (61%) and Witvlag (73%)), however, in Khalavha Site 1, the correlation was relatively weak (49%) (*Table 2*).

The species composition of total woody plants and their seedlings can be similar in various habitats, including both closed and open canopies (Sharma et al., 2016). In the current study, bush tea plants and their seedlings were noted to occur in plant communities that were composed other broad-leaved and grass species. However, the assessment of density, frequency and density was only focused on bush tea individuals. Species with fast growth rate have greater potential of making a higher ground cover percentage over a shorter period of time. All the surveyed sites were dominated by both shrubs and grasses during all survey times.

It is important to take into consideration that other key factors such as climatic factors, soil fertility and plant characteristics play a role in the growth of plants in the wild. Previous studies on climatic conditions demonstrated that rainfall, relative humidity and temperature determined plant height, stem diameter and leaf number in wild bush tea in the Limpopo Province (Tshikhudo et al., 2019). In terms of soil fertility fertilizer combinations of 300 N, 300 P and 200 K (kg ha^{-1}), an increased fresh and dry

shoot mass, number and area of leaves, as well as the concentrations of total polyphenols in bush tea plant were reported, regardless of the season (Mudau et al., 2007a).

Conclusion

From this study, in general, based on the different growth stages of bush tea plant, its distribution along road sides at Haenertsburg, Witvlag, Khalavha Site 1 and Khalavha Site 2 was common in plant communities with other plant species. Bush tea plants showed optimum values of density, frequency and abundance in most plant communities in all study sites. Bush tea plants seem to have a good competitive ability to actively grow in the wild, together with other plant species. The bush tea plant height, stem diameter and number of leaves per plant significantly increased as the survey seasons progressed. In all study sites, the bush tea growth parameters (height, stem diameter and number of leaves) positively correlated with ground cover, species richness, bush tea density, frequency and bush tea abundance. This study has provided an understanding of the influence of ecological factors on bush tea's growth in a plant community. Effect of ecological parameters such as ground cover, species richness, density, frequency and abundance should not be neglected when determining competitive ability of bush tea during commercial cultivation. However, future studies should be conducted to investigate the phyto-sociological survey on weed species together with bush tea plants.

Conflicts of Interests. The authors declare that they have no conflicts of interests.

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