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Influence of Forest Canopy Gaps on Establishment of *Mikania Micrantha* Kunth, an Invasive Plant, in a Tropical Forest in Southern Western Ghats, India

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Abstract Tropical forests are more resistant to plant invasion. However, reports of the occurrence of invasive alien plants within tropical forests have surged in recent years. The invasibility of the tropical forest ecosystem is enhanced with the disturbance mediated environmental fluctuations. The upwelling of natural light on the forest floor and associated resource fluctuation due to canopy gaps facilitate the establishment of light tolerant, invasive plants. Here the authors report the effect of the canopy gap on the establishment of *M micrantha* in a protected forest in Kerala, India. A significant direct relationship between the abundance of *M micrantha* with canopy openness and light intensity reveals how the forest canopy gap in the study area acts as a gateway to plant invasion.

Keywords: *biological invasion, invasive plants, tropical forest, canopy gap, light intensity, Mikania micrantha*

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1. Introduction

Biological invasion is a creeping disaster in which a species rapidly adapts itself in new geographic regions where it has not been previously reported and causes serious ecological damages [1,2,3,4]. As a major driver of global environmental change [5,6] biological invasion imposes various threats to many ecosystems in the world [3,7,8]. The tropical forestsare no exception [9]. Highly specialized, narrow niches of inhabiting species bestow natural resistance to tropical forests against biological invasions [10,11]. However, many authors have reported plant invasion within tropical forests [12-17]. Tropical forests are rich in biodiversity and harbor almost two-thirds of terrestrial biodiversity [18,19]. The high diversity and structural complexity of undisturbed tropical forests act as a shield that restricts the entry and establishment of invasive plants [9,10,20]. Natural or otherwise, fissures in the protective shields increase the invisibility [10,21,22,23] and consequently the susceptibility of the ecosystem to biological invasion.

Invasibility has long been identified as one of the most important factors that influence biological invasion [24]. Land conversion, land use intensification, habitat fragmentation, altered disturbance regime (especially fire), altered hydrological flow. and defaunation [19,25,26] are the other factors that aid invasion. This paper focuses on canopy gap formation and its effects on plant invasion in a tropical forest.

Canopy gap formation is a common disturbance reported from the tropical forest [27]. It can be either natural or manmade. Natural canopy gaps result from tree-fall or break of large branches [27,28]. Forest clearing by logging results in manmade canopy gaps [29]. The tropical forest canopy is shaped by long-term adaptation to the local climatic condition [30]. Climate change, leading to a higher frequency of cyclonic storms, landslip, and forest fires result in abrupt changes in canopy gap [31].

The gap formation in the tropical forest causes fluctuations in various eco-physical factors [32] that alter the prevailing microclimatic condition. In effect, it increases the availability of sunlight [33], soil moisture [34,35], soil nutrients [36]. The biotic changes include the disruption of species interaction and diminishing [21] These abiotic and biotic changes enhance the invasibility of tropical forests [23]. It favors invasive plants with early colonizing traits to establish within the forest gaps [37,38,39]. Many researchers have studied various aspects of plant invasion in Indian forests [14,16,40,41,42,43]. Sajeev et al [44] prepared a checklist of invasive plants present in the forests of Kerala. Among them, *Mikania micrantha* Kunth is one of the high-risk invasive plants. In this study, we focused on the invasion of *M micrantha* in a legally protected forest in the Southern Western Ghats. The objective of the study was to investigate the influence of forest canopy gaps and light intensity on the establishment of *M micrantha*

2. Methodology

2.1. Study Area

The study was carried out at the Peppara Wildlife Sanctuary (77 6’ 50” and 77 14’ 5” E and 8 34’ 30” and 8 41’ 25” N) Kerala, India (Figure 1). The Peppara Sanctuary is a part of Agasthyamalai Biosphere Reserve in the southern tip of the Western Ghats. The region has a tropical hot and humid climate with temperature ranging from 16ºC to 35ºC and an annual mean rainfall of 2500 mm. Forest types in Peppara Wildlife Sanctuary include west coast tropical evergreen forest, southern hilltop tropical evergreen forest, west coast semi-evergreen forest, Southern moist mixed deciduous forest, myristica swamp forest, sub-montane hill valley swamp forest, and riparian forests etc. With a wide range of flora and fauna, this sanctuary forms a critical component of a significant conservational complex in the Western Ghats[45]. For the present study, we identified an open semi-evergreen forest type located near the reservoir [46].

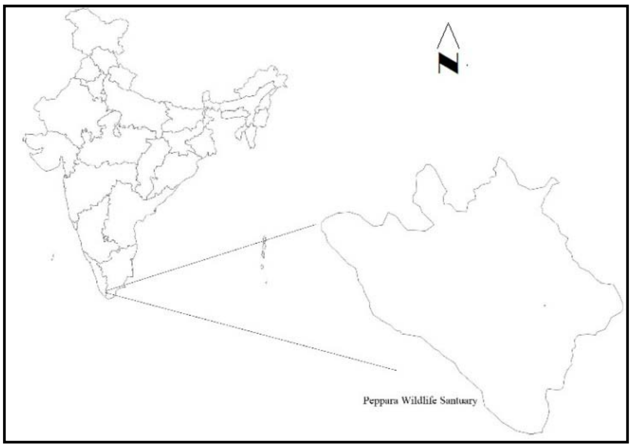

Figure 1. Study area Peppara Wildlife Sanctuary

2.2. *Mikania micrantha* Kunth

Mikania micrantha (aka mile-a-minute) is a perennial invasive climber belonging to Asteraceae. It is native to tropical South and Central America and is considered as one of the worst invasive species in the world [47]. *M micrantha* establishes in degraded habitats, along roadsides and railway tracks, abandoned/ unmanaged plantations, secondary forests, barren farmlands, along the banks of water bodies/ rivers [48,49]. The package of inherent traits of rapid vegetative growth, physiological efficiency and allelopathy makes *M micrantha* a prolific invasive species [50,51,52]. *M micrantha* grows at an alarming rate and smothers the native plants. Mode of reproduction can either be sexual or asexual. *Mikania micrantha* produces minute seeds from October to April, which are easily dispersed either by wind, animal, or water current. Seed production in a matured mother plant varies from 35,000 - 55,000 seeds in a year [53,54] As an early colonizer, it is tolerant to the high light condition. *M micrantha* can be potentially grown as a cover crop in rubber plantations and sloppy terrains to check soil erosion. However, the benefits are meagre compared to the ecological and economic impacts caused due to its invasion [54].

2.3. Field Survey and Measurements

2.3.1. Sampling of *M micrantha*

A reconnaissance survey was carried out in the study region to identify forest canopy gaps. Based on ease of accessibility we selected 21 forest canopy gaps for further studies. Site surveys were carried out from November - December 2017 to record the abundance of *M micrantha* in the forest gaps and adjacent non-gap sites. Quadrats (8 m × 8 m) were laid over the survey plots (gap and non-gap sites). Within the quadrats, we placed 1m × 1m sub quadrats randomly to record the abundance of *M micrantha* *[33]*. The Braun-Blanquet cover-abundance scale (BB scale) [55] was used to assess the abundance of *M micrantha* (Table 1).

Table 1. Braun-Blanquet cover-abundance scale

Braun-Blanquet score	Range of cover (%)
5	75-100
4	50-75
3	25-50
2	5-25
1	<5; numerous individuals
+	<5; few individuals

2.3.2. Measurement of Forest Canopy Gap Openness and Light Intensity

We captured hemispherical images in a skyward direction using a fisheye lens mounted on a smartphone (Apple iPad mini 2) held perpendicular to the ground from the center of each gap and non-gap sites (Figure 2). Percent canopy openness of the respective sites was estimated using Gap Light Analyzer (GLA) [56].

Light intensity in the photosynthetically active radiation (PAR) available in each gap and non-gap sites was measured as photosynthetic photon flux density (PPFD; µmol m^{-2} s^{-1}) using a Quantum Sensor (MQ-500, Apogee Instruments). Hourly measurements of light intensity carried out for 12 hours, from 6 AM to 6 PM on a clear sky day of each month from June 2017 to May 2018, were taken as the representative PPFD value for the month.

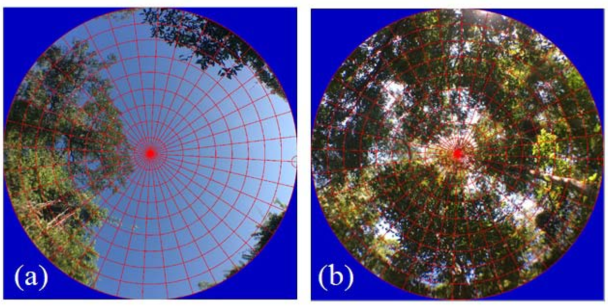

Figure 2. Hemispherical images used for the estimation of canopy openness of (a) gap site (canopy openness 69%) (b) non gap site (canopy openness 17.5 %)

2.3.3. Topographic Data

The geographic coordinates and elevation value of all sampling sites were recorded with GPS (Garmin eTrex 20). Aspect values were derived from ASTER DEM data. We classified the aspect into four directions as N (315°- 45°), E (45°-135°), S (135° - 225°), and W (225° - 315°). (Figure 3). QGIS 3.10.0 was used for the topographic analysis.

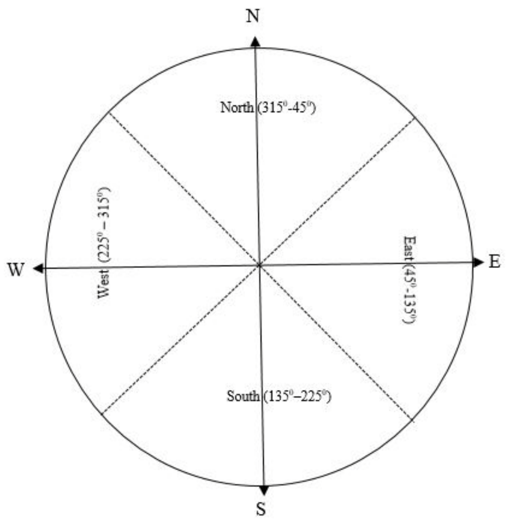

Figure 3. Classification of aspect direction

2.3.4. Statistical Analysis

The distribution of quality-checked data was studied to select appropriate statistical analysis. Descriptive statistics of canopy openness, light intensity and elevation were computed. The circular mean was taken as the representative central value for aspect [57]. While conventional *t-test* was used to compare the mean elevation, the Watson-Williams test for two samples [58] was used to compare the mean aspect value of sites with and without the presence of *M. micrantha*. The relationship of the abundance of *M micrantha* with canopy openness and light intensity was expressed as the corresponding Karl Pearson correlation coefficient. The analysis was carried out in R

3. Results

3.1. Topography and Occurrence of *M micrantha*

Among the 21 forest canopy gaps surveyed, *M micrantha* was observed in 13 gaps. Table 2 illustrates the invasion status (presence/absence of *M micrantha*) and the topographic characteristics of the gaps surveyed. *M micrantha* was mostly confined to the forest gaps at lower elevations. Site elevation of the study area appears to be a factor that influences invasion of *M. micrantha*. It is evident from Table 2 that lower elevation sites were more susceptible to *M. micrantha* invasion. The mean elevation of the invaded and the un-invaded forest canopy gaps (146.3m and 165.8 m) were significantly different at 95% confidence level.

Among the invaded sites, the North and South facing sites constituted 38.5 % and 31% respectively. While a quarter of invaded sites was W facing (23%), the E face was relatively less invaded (8%).Half of the uninvaded gap sites were West facing. The mean of the aspect of invaded gap sites (283.4) was not significantly different from that of uninvaded gap sites (260).

Table 2. Invasion status and the topographic characteristics of the forest canopy gaps surveyed

SNo	Gaps	Mikania -status	Elevation (m)	Aspect (degree)	Facing
1	G1	1	121.8	11	N
2	G2	1	150.6	354	N
3	G3	1	140.6	274	W
4	G4	1	158.0	326	N
5	G5	1	168.0	64	E
6	G6	1	149.1	340	N
7	G7	1	139.4	204	S
8	G8	1	139.7	228	W
9	G9	1	138.4	180	S
10	G10	1	139.2	186	S
11	G11	0	165.3	158	S
12	G12	1	142.4	173	S
13	G13	1	155.6	294	W
14	G14	1	158.8	320	N
15	G15	0	155.6	198	S
16	G16	0	141.6	144	S
17	G17	0	134.6	308	W
18	G18	0	173.6	302	W
19	G19	0	180.1	275	W
20	G20	0	179.3	270	W
21	G21	0	196.1	326	N

0-Absent, 1- Present.

3.2. Abundance of *M micrantha*, Canopy Openness and Light Intensity

Table 3 & Table 4 describe the abundance of *M micrantha* and eco-physical variables *viz.* canopy openness and light intensity measured in the invaded forest canopy gaps and the non-gap sites (closed canopy) respectively. The abundance of *M micrantha* measured as percentage coverage in Braun-Blanquet scale (BB Scale) in the forest gaps varied from 2 to 5. While the higher abundance of *M micrantha* was observed at GP1 (75-100%), the least was observed at GP3 (5-25%). A majority of the gaps had moderate coverage (25-50%). GP2, GP4, GP5, GP6, GP8, GP11 GP12 and GP13 recorded 25-50% cover (BB score 3) in BB scale and GP7, GP9 and GP10 recorded BB score 4 (50-75%). Intact canopies (non-gap areas) seem to resist *M micrantha* invasion (Table 4).

Forest canopy gaps ranging from a third (39.5%), to almost open canopies (97.4%) constituted canopy gap sites. Closed (intact) forest canopy sites had less than 10% to slightly more than 20% canopy gap. The mean canopy openness of the invaded and uninvaded forest canopy gaps was 73.3% and 17.03 %, respectively. The highest canopy openness was observed at GP7 (97.4%) and the lowest at GP3 (39.5 %). The mean annual light intensity (PAR) measured in the forest canopy gaps was 701 (±80.5) μ mol m^{-2} s^{-1}. The study area receives maximum PAR during pre-monsoon season (938 ±130.4 μ mol m^{-2} s^{-1}). The lowest PAR influx was recorded during the monsoon season (558 ±50.5 μ mol m^{-2} s^{-1}). The post-monsoon season has an intermediate level of PAR (607 ±67.4 μ mol m^{-2} s^{-1}). GP7 received the highest annual PAR (808 μ mol m^{-2} s^{-1}), and the least was recorded at GP3 (511 μ mol m^{-2} s^{-1}). The annual mean PAR available in the non-gap sites was very low (70.5±32.3 μ mol m^{-2} s^{-1}). While NP4 received the highest PAR (145 μ mol μ mol m^{-2} s^{-1}), NP10 reported the least PAR (35.3 μ mol μ mol m^{-2} s^{-1}).

The correlation matrix (Table 5) shows the strong and significant positive relationship of the abundance of *M micrantha* with canopy openness (r= 0.81) and light intensity (r = 0.85); *p*= 0.01. Canopy openness and light intensity were also highly correlated (r= 0.95). Gaps with more than 80 % openness and annual light intensity above 740 μ mol m^{-2} s^{-1} were highly invaded by *M. micrantha* (BB score > 4). The maximum growth of *M micrantha* (BB5) was found in a gap site where the mean annual PAR was 807 μ mol m^{-2} s^{-1}, and with 88% open canopy. Forest canopy gap with 39.5 % openness and PAR of 511 μ mol m^{-2} s^{-1}, recorded the least coverage of *M micrantha* (BB score 2). Though *M micrantha* was non-existent in the majority of the non-gap sites, a few instances of occurrence were noted in some sites (<5% - a few individuals).

Table 3. Abundance of *M micrantha*, canopy openness and light intensity measured in the invaded forest canopy gaps

SNo	Code	Canopy Openness (%)	Abundance of *M micrantha* (BB scale)	Light intensity (PAR) μmol m^{-2} s^{-1}			
				Pre Monsoon	Monsoon	Post Monsoon	Annual Mean
1	GP1	88.0	5	1090	620	712	807
2	GP2	59.5	3	810	520	550	627
3	GP3	39.5	2	648	422	464	511
4	GP4	59.8	3	805	534	575	638
5	GP5	71.0	3	930	580	605	705
6	GP6	68.7	3	975	560	575	703
7	GP7	97.4	4	1107	620	696	808
8	GP8	79.5	3	875	564	584	674
9	GP9	81.0	4	1015	587	607	736
10	GP10	92.2	4	1056	586	684	775
11	GP11	72.7	3	980	550	575	702
12	GP12	78.9	3	1012	564	656	744
13	GP13	64.7	3	896	548	607	684
Mean (±SD)		**73.3 (±15.5)**	**--**	**938(±130.4)**	**558(±50.5)**	**607(±67.4)**	**701(±80.5)**

Table 4. Abundance of *M micrantha*, canopy openness and light intensity measured in the non-gap sites

SNo	Code	Canopy Openness (%)	Abundance of M micrantha (BB scale)	Light intensity (PAR) μmol m^{-2} s^{-1}			Annual Mean
				pre-monsoon	*monsoon*	*post-monsoon*	
1	NP1	18.0	+	64	58.2	61.2	61.1
2	NP2	17.5	--	58	51	60	56.3
3	NP3	17.3	--	62	48	54	54.7
4	NP4	22.3	+	180	120	135	145.0
5	NP5	21.5		142	105	124	123.7
6	NP6	11.9	--	52	36	48	45.3
7	NP7	14.8	--	55	43	46	48.0
8	NP8	13.1	--	58	44	49	50.3
9	NP9	15.6	+	62	45	53.6	53.5
10	NP10	9.5	--	40	31	34.8	35.3
11	NP11	20.3	+	95	76	83	84.7
12	NP12	18.5		76	63	69	69.3
13	NP13	21.2	--	98	82	88	89.3
Mean ±SD		**17.03±3.9**		**80.2+40.1**	**61.7±27**	**69.7±30**	**70.5±32.3**

Table 5. Correlation of *M micrantha* Abundance, Canopy openness and Light intensity in the forest canopy gaps

	M micrantha abundance	Canopy openness	Light intensity
M micrantha Abundance	--		
Canopy openness	0.81	--	
Light intensity	0.85	0.95	--
Significant at the 0.01 level (2-tailed).			

4. Discussion

4.1. Topographical Factors and Occurrence of *M micrantha*

Analysis of elevation and aspect of the forest canopy gap sites revealed the topographical preference of *M micrantha* to establish within the study site. Forest canopy gaps at the lower elevation were found to be more prone to *M micrantha* invasion. It corresponds with the previous observation that *M micrantha* thrives better at lower elevations [51]. Forest canopy gaps act as a gateway that let wind-dispersed seeds of *M micrantha* easily descend to the forest floor. Further, the adjacent reservoir enhances the invasibility of the study region through its modulating effect on microclimate [59] and soil moisture [60].

The influence of the slope-aspect on the process of succession and invasion is previously documented [61-66] The difference in solar irradiance on the north and south aspects are also well understood [64]. In the Northern hemisphere, the south facing regions receive prolonged solar irradiance than their diametrically opposite counterparts. Consequently the north facing aspects tend to become more humid [61,64]. A majority of the invaded forest canopy gap sites in the study region were in North facing slopes. However, the proportion of *M. micrantha* invasion in the South facing slopes was substantial, albeit lesser than the North facing slopes. *M. micrantha* were randomly distributed in forest canopy gaps with different aspects in the study region. We attribute the randomness to proximity of the study area to the equator, and consequent minimal difference in solar irradiance received on different aspects [64,67]. Irrespective of aspect; forest canopy gaps in the study area are vulnerable to invasion by *M micrantha.*

4.2. Forest Canopy Gaps, Light intensity and Establishment of *M micrantha*

The role of disturbance in promoting plant invasion in the tropical forest is well known [9,10,11]. The present study revealed the role of forest canopy gaps in the recruitment and establishment of *M micrantha* at the study region. Similar results were reported for forests elsewhere [33,39,68,69]. The establishment of *M micrantha* in forest canopy gaps is a successional response to natural or anthropogenic micro-level disturbances. Usually, canopy gaps promote forest regeneration through a series of successional events [70,71,72]. The forest canopy gap caused due to natural tree fall or logging, dramatically alters the light regime in the forest floor, which in turn, increases environmental heterogeneity and uncertainties in resource availability [73]. Increased light availability changes soil temperature, moisture, and influences microbial activity and nutrient mineralization [33,35,74,75]. In addition, decomposition of fallen trees temporarily increases nutrient availability [76]. Along with competitor-free environment, these abiotic changes render the forest more invadable, and paves the way for emergence of early colonizing invasive plants [77].

The strong direct relationship between canopy openness and the presence of *M micrantha* reveal the canopy gap dependency of plant invasion. Large forest canopy gaps support a higher population of *M micrantha*, and harbors higher diversity of invasive species [78]. Solar irradiance, which is positively correlated with the gap size, is the most important factor in determining the seeding density in forest gaps [79,80,81]. The amount of light entering the forest gaps depend on various factors, including size and topographic position of the gap, height of the surrounding canopy, sun angle, sky and condition [79,82,83]. Due to the high direct correlation between canopy gap size and light levels [84], the former is used as a surrogate of light availability [79,85] and both are used as good predictors of exotic species [33]. In this study, we observed a strong positive relationship between the abundance of *M micrantha* and light intensity (PAR). Further, the varying abundance of *M micrantha* in forest gaps and non-gaps sites indicates how light intensity is essential for its establishment. Like many photophilous invasive plants, *M micrantha* was distributed in a light gradient with high abundance in the forest gaps and lower under non-gaps (closed canopy) in the Peppara Wildlife Sanctuary. The reduced light availability under extreme shade restricts the growth of *M. micrantha* [86,87].

5. Conclusion

Understanding the influence of extrinsic factors as determinants of species invasion is crucial for the management of invasive plants. The present study revealed that the establishment of *M micrantha* in the Peppara wildlife sanctuary was facilitated by the forest canopy gaps. *M. micrantha* establishes as patches in forest canopy gap sites, from where they spread gradually. The thick carpet of *M micrantha* on the forest floor interferes with the natural gap regeneration and poses a severe threat to the forest ecosystem. In this study, we found a strong positive relationship between the abundance of *M micrantha* in forest canopy gap and light intensity. The study also revealed some cues on the role of topography in plant invasion. A detailed survey of the topography and other extrinsic factors like soil moisture, temperature, and availability of nutrients in the forest gaps will draw more inferences on plant invasion in the tropical forest.

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