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The Effects of Landscape Elements on the Breeding Sites of Bloodsucking Midge

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Abstract: *Forcipomyia taiwana*, a bloodsucking midge that is one of the most irritating biting pests in Taiwan, has raised widespread public concern. However, we have little information about the extent to which landscape factors affect their potential habitats. As a result, landscape professionals do not have enough information to implement preventive strategies to control midges. The purpose of this study is to investigate the relationship between landscaping and algae growth for larval breeding sites of *Forcipomyia taiwana*. The intent is to determine the environmental strategies that make the planned landscape unsuitable for midges to breed. GIS based on data collected from 16 constructed landscape sites (317,187 m^2 in total) was utilized to spatially examine the relationship between the occurrence of the algae for midge breeding sites and the ground surface types and planting characteristics in each landscape. The results revealed that the potential midge habitats can be controlled through careful selection of the ground surface, the improvement of the site drainage, and choosing plants with the appropriate characteristics. Apart from choosing the appropriate type of paving surface, the integrity of the paving installation and the coverage of the ecological surface also influence prevention efficacy.

Keywords: landscape management; landscape design; landscape material; landscape planning; spatial analysis; *Forcipomyia taiwana*; bloodsucking midge

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1. Introduction

Bloodsucking midge (*Forcipomyia taiwana*), commonly called the "little black mosquito", is a major pest typically found in warm and humid areas of Taiwan. The female adults feed on human blood, usually attacking the exposed parts of the body, such as hands, feet, the face, and calves. *F. taiwana* are active in the daytime and are about 1.4-mm long. Their tiny size makes them difficult to detect even when they are on people's skin. Physical reactions to their bite include itching and swelling that lasts several days. Depending on the individual, their bites can also trigger allergies [1].

These midges have aroused widespread public concern. Studies have indicated that unsuitable landscape planning can increase *F. taiwana* [2–5], but there is little specific research on the relationship between landscape composition and the midge's breeding habitats. There is a paucity of information about relevant environmental factors. As a result, landscape professionals do not have enough information to implement preventive strategies to control midges in the early stages of site preparation. This study analyzes the relationship between landscape factors and the larval breeding sites of *F. taiwana*. The study attempts to determine the environmental management strategies that will make the designed landscape unsuitable for larval breeding sites.

Because *F. taiwana* feeds on human blood, the presence of human beings and their activities become important for the midges' breeding. With the warm and humid weather conditions and dense human population in Taiwan, the *F. taiwana* covers a wide area, including eastern, central, and southern Taiwan, with high concentrations in the counties of Tauchun, Chumhaw, Yinlin, and Tainan [6,7].

The various landscapes of Taiwan not only sustain our environmental quality, but also offer people the opportunity to get in contact with nature, conduct outdoor activities, relax, and engage in physical exercise [8]. All this is particularly necessary in the densely populated and urbanized environment of Taiwan [9]. However, since the midges' active times overlap with the periods when people are in outdoor settings, there are many reports of people being bitten by dense swarms of midges during their stays in the outdoors, causing adverse reactions of allergies and skin irritation. Although insecticide can temporarily reduce the population of midges [3], this also arouses public health concerns and, in any case, the midge population rebounds after a temporary reduction [6]. Thus, a more sustainable and salubrious management strategy needs to be developed.

F. taiwana is a diurnal insect and is often less active at heights over two meters. The bloodsucking activity cycle starts around 8:00 a.m., with activity peaking between 12:00 and 3:00 p.m., ceasing at about 6:00 p.m. [10,11]. The optimum temperature for *F. taiwana* ranges from 18 °C to 27 °C. The population fluctuates according to the season. The midges are most populous during summer, least so in winter. A spike often occurs during the spring rainy season [2]. Studies have found that the population of *F. taiwana* is directly related to temperature, rainfall, rainfall days, and monthly temperature [12]. A similar conclusion was drawn in a study in Hawlian, Taiwan, indicating that the midge population changes in relation to rainfall, humidity, and temperature. For instance, *F. taiwana* decreases when the temperature is higher than 35 °C, lower than 10 °C, or when the moisture is excessive [3].

The midges are mainly found in hills and low altitude mountains in Taiwan and Mainland China. An earlier Mainland China study reported a case of the female *F. taiwana* carrying the Japanese encephalitis virus [13]. However, there is insufficient evidence to categorize *F. taiwana* as a disease-carrying insect. Recent studies have found an increase in population. A secular analysis of studies reveals that the elevation ranges of *F. taiwana* have expanded from 150 m in earlier records to 200–400 m, with the most recent surveys recording 350–400 m [2,7]. The newer studies find that approximately 78% of the population are in areas under 250 m, and 15% are distributed between 250 and 500 m [3]. In addition, the area coverage has expanded to cover almost all counties in Taiwan [2,12]. This expansion has been attributed to global warming [2,12].

F. taiwana is a completely metamorphic insect. Its life cycle follows the standard four stages of egg, larva, pupa, and adult. Most eggs hatch within three days, and then go through 16–18 days of the larval stage and 3–5 days of the pupal stage to become adults. The period before the adult stage is in the range of 21–26 days, and the adult can live for another 22–26 days [14]. The male adult feeds on dew or nectar, while the female adult feeds on human blood. The daily blood-feeding period for females is four to six minutes, and the female lays about 30 to 40 eggs in a scattered manner after three or four days feeding on blood. The length of the brown-black color eggs is approximately 0.3 mm. The larva is terrestrial and forms pupas in dry locations. In the last stage, the adult frequently inhabits bushes or lower trees to wait for hosts [4].

Since the midge cannot fly very well, most adults stay close to their larva site. A study found that the adult population is concentrated within a 100 m range from their larva sites, with most populations remaining within 300 m. The observed population significantly decreases the further the midges are from their larva sites [4].

The midge larva feeds mainly on blue-green algae, green algae, and other algae in the breeding sites [6,11,15]. Most of the consumed algae species visually appear green as they contain chlorophyll and carry out photosynthesis. The algae need suitable micro-climates and sunlight and usually grow on different ground surfaces, such as brick, concrete, or bare soil [16]. One study has indicated that ground covers such as sand and soil with low level moisture tend to have fewer larvae [5]. By contrast, ditches, fencing walls, and shaded areas close to residences with indirect sunlight and a high level of moisture are more accommodating for growing algae for breeding *F. taiwana* larvae [17].

F. taiwana has been observed to favor two types of land. One is agricultural land use, such as bamboo and betel nut farms. Another is landscaped green spaces, such as schools and parks [6,12]. The active range of *F. taiwana* is linked to the distance to larva sites, as well as the regular presence of human beings [17]. The frequency of human activity significantly affects the midges' population density [13]. The environments that have sufficient blood sources from people's residences and activities, such as parks, recreation areas, schools, and agricultural communities, are potential locations for dense *F. taiwana* populations.

F. taiwana usually bites uncovered human skin, such as the face, neck, lower neck, foot, and hand. The bitten spot usually manifests a wheal with itchiness within an hour, and the bite may lead to a delayed type of hypersensitivity with blisters, pustules, itchy eruptions, or sometimes allergies that need medical treatment [1]. The landscape spaces infested by *F. taiwana* are often associated with frequent human activities [18], and the dense midge activities can discourage visits to recreation areas and outdoor public spaces.

Green spaces have important functions that sustain ecological values, display nature's beauty, and are excellent settings for recreation and educational activities. However, inappropriately designed landscapes may also possibly become environments that allow the growth of algae as food for the larvae of *F. taiwana* [3,19]. Thus, landscape management is proactively seeking design strategies to create green spaces while preventing the occurrence of *F. taiwana*. Unfortunately, there are insufficient studies to provide a solid basis for possible solutions. As a result, landscape and planning professionals find it difficult to factor this consideration into their designs and choices of materials.

Therefore, the aim of this study is to understand the effects of landscape factors on the larva breeding site of *F. taiwana* using algae growth as the indicator. The study makes an empirical examination of the effects of different ground surface types and planting features, such as tree and shrub heights, shading conditions, and adjacency to structures. We used the method of spatial analysis and GIS to explore the sustainable preventive strategies. The objective is to identify the pertinent factors in constructed landscapes associated with the formation of larval breeding sites. These data will assist in sustainably mitigating the population of bloodsucking midges from a landscape planning and design perspective.

2. Materials and Methods

2.1. Study Site

The study sites include 16 constructed landscape sites of public parks and schools located at Shetou Township, Changhua County and Zhongpu Township, Chayi County, Taiwan (Figure 1). Based on survey reports, these regions have significant infestations of *F. taiwana* [2]. The total area of study sites is approximately 31.7 Ha (317,187 m^2), with the elevation ranging from 100 to 300 m. The sites are level and smooth, with a slope ratio between 3% and 12%. The monthly temperatures average between a low of 16.5 °C and a high of 28.6 °C. The average yearly rainfall is approximately 1700 mm, and the relative humidity is approximately 80%.

The sites are generally used as public recreational areas or school outdoor settings, offering a combination of green areas and facilities, including various types of vegetation, trails with different paving materials, restrooms, squares, pavilions, and shelters.

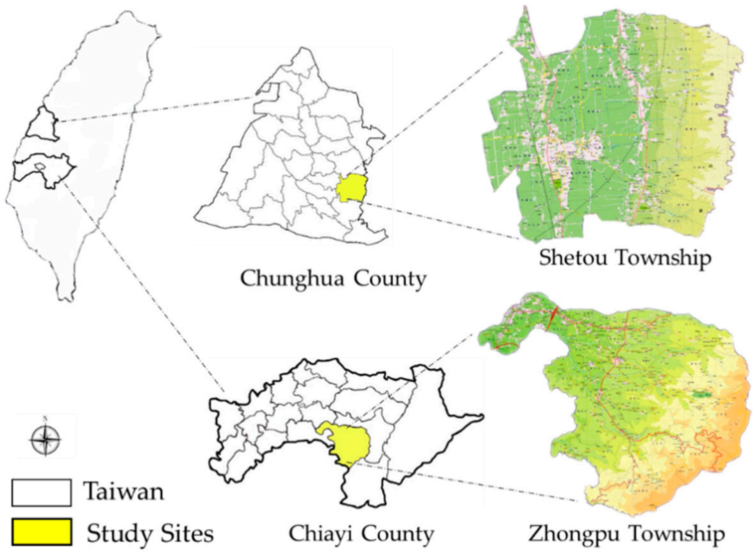

Figure 1. Study site location.

2.2. Data Collection and Analyses

Data collection utilized an empirical field survey. In preparation for the field survey, the researchers first generated the site plan drawings by measuring individual sites and digitalizing the drawings into GIS to construct the spatial layout for each sample site. The data collection process was conducted from May to July. In the field survey, the surveyor first measured and recorded the pre-identified landscape variables. Algae growth locations were noted and identified in the field by form, color, and morphological features through observation by the naked eye assisted with a magnifier. A similar method was used to identify the types of ground surface. For vegetative factors, a laser rangefinder and a measuring tape were used to measure the tree and shrub heights and intervals. In addition, the researchers adopted a two-step method to identify the shading conditions of trees and shrubs. This involved standing under the tree canopy and taking a digital photo with the camera lens pointing to the sky, and then identifying the shading levels by the light penetration areas in the photo. A similar method was used to identify the shrub shading with the lens facing down.

The data included the spatial and attributive data of ground surface types, tree and shrub heights, tree and shrub shading levels, distances between the ground and the shrub's first branch, and the adjacency to buildings and pavilions. The variables are listed in Tables 1 and 2.

Subsequently, the collected raw data were entered into a spatial database as GIS layers with their attributive types using the vector data format. Then, a 1 m $\times$ 1 m grid was superimposed on the data map to extract the algae growth spots and the types of tested variables in each grid. The total sample size is 317,187. For statistical analysis, logistic regression was applied to analyze which variables related to algae habitat for the bloodsucking midges and to what extent.

Table 1. Ground surface types.

Category	Type	
Concrete	1.	Concrete
	2.	Open concrete ditch
	3.	Close lightly pebbled
Asphalt	4.	Asphalt
Brick	5.	Permeable brick
	6.	Newly installed permeable bricks
	7.	Red brick
	8.	Tile
Rock	9.	Rock slab
Plastic	10.	Plastic pad
	11.	Polyurethane (PU)
Leaf mulch	12.	Single layer leaf mulch
	13.	Multi-layer leaf mulch
	14.	Thick leaf mulch
Soil mix/loose material	15.	Pebble gravel sand on bare-soil
	16.	Gravel sand on compacted soil
	17.	Thin sand on compacted soil
	18.	Stabilized planting soil
	19.	Compacted soil
	20.	Active planting soil
	21.	Clay
	22.	Loose brick gravel
Ground cover	23.	Meadow
	24.	Lawn
	25.	Spotty lawn
Wood	26.	Wood
Others	27.	Pond (not as surface)
	28.	Roof (not as surface)

Surface Type Photos


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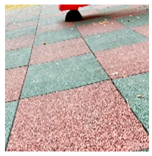
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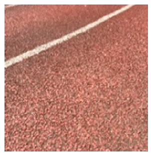
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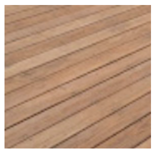
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Algae

Table 2. Vegetative characteristics and adjacency types.

Vegetative Characteristics		Levels
Tree	Height	5 levels: 0, 1–3 m, 4–6 m, 7–9 m, ≥10 m
	Shade level	4 levels: open, little shade, half shade, much shade
Shrub	Height	5 levels: 0, 0.2–0.5 m, 0.6–1 m, 1.1–2 m, ≥2 m
	Distance of first branchto ground	5 levels: 0, 0–5 cm, 6–10 cm, 11–20 cm, 21–30 cm
	Shade level	4 levels: open, little shade, half shade, much shade
Adjacency types		3 types: open, pavilion, building (adjacency buffer 5 m)

3. Results

The result of the Omnibus test presents that the model fit is significant at $\chi 2$ = 24,758.624 and $p < 0.001$. The predictors are significant in the model level as well, which indicates that the tested landscape factors impact algae formation.

Among the landscape factors, the results show the striking effect of ground surface types on algae growth in our test (Table 3). The findings indicate that ground surface characteristics have much stronger effects on facilitating algae growth, while immediacy to structures and vegetation conditions show much less impact in either a positive or negative direction with respect to algae growth (Tables 3 and 4).

Table 3. Effects of ground surface types and adjacency types on algae occurrence.

		Coefficient	Standard Error	Wald Statistic	*p*-Value	Odds Ratio	Effect Order
	Ground surface type			12,490.421	<0.001		
Concrete material	Concrete	3.834	0.279	189.392	<0.001	46.233	7
	Concrete ditch	6.356	0.287	490.079	<0.001	576.210	1
	Close lightly pebbled	2.586	0.302	73.530	<0.001	13.279	16
Asphalt	Asphalt	1.462	0.303	23.228	<0.001	4.316	20
Brick material	Permeable brick	2.632	0.280	88.636	<0.001	13.902	15
	Newly installed permeable brick	2.147	0.496	18.736	<0.001	8.558	17
	Red brick	2.809	0.365	59.253	<0.001	16.586	13
	Tile	−1.986	1.038	3.661	0.056	-	-
Rock	Rock slab	3.164	0.363	76.060	<0.001	23.677	12
Plastic material	Plastic pad	−14.948	7420.966	0.000	0.998	-	-
	PU	−0.027	0.353	0.006	0.938	-	-
Fallen leaf mulch	Single layer leaf mulch	3.199	0.295	117.748	<0.001	24.500	11
	Multi-layer leaf much	3.423	0.283	146.100	<0.001	30.663	9
	Thick leaf mulch	0.504	0.322	2.444	0.118	-	-
Soil mix/loose material	Pebble gravel sand on bare-soil	2.672	0.387	47.554	<0.001	14.466	14
	Gravel sand on compacted soil	3.282	0.331	98.405	<0.001	26.637	10
	Thin sand on compacted soil	5.986	0.290	424.736	<0.001	397.921	2
	Stabilized planting soil	4.431	0.385	132.638	<0.001	83.982	6
	Compacted soil	4.965	0.279	317.071	<0.001	143.349	3
	Active planting soil	2.052	0.765	7.184	0.007	7.781	19
	Clay	3.574	0.309	133.444	<0.001	35.654	8
	Loose brick gravel	4.635	0.282	270.406	<0.001	103.019	4

Table 3. *Cont.*

		Coefficient	Standard Error	Wald Statistic	*p*-Value	Odds Ratio	Effect Order
Ground cover	Lawn	0.720	0.284	6.451	0.011	2.055	21
	Spotty lawn	4.536	0.280	262.516	<0.001	93.325	5
	Meadow	2.117	0.295	51.527	<0.001	8.310	18
Wood material	Wood	−0.188	0.762	0.061	0.805	-	-
	Pond	−14.640	5684.144	0.000	0.998	-	-
	Building	0.366	0.289	1.607	0.205	-	-
	Adjacency types			538.400	<0.001		
	Pavilion	0.940	0.056	277.022	<0.001	2.560	
	Building	0.851	0.049	299.938	<0.001	2.343	

Table 4. Effects of vegetation characteristics on algae occurrence.

Vegetation Characteristics	Coefficient	Standard Error	Wald Statistic	*p*-Value	Odds Ratio
Tree height			148.722	<0.001	
1–3 m	−0.321	0.097	10.844	<0.001	0.726
4–6 m	−0.507	0.066	59.544	<0.001	0.602
7–9 m	−0.337	0.072	21.871	<0.001	0.714
≥10 m	−0.701	0.071	96.383	<0.001	0.496
Tree shade			376.847	<0.001	
Little shade	0.370	0.107	11.935	0.001	1.447
Half shade	0.829	0.067	153.808	<0.001	2.291
Much shade	1.151	0.066	303.578	<0.001	3.160
Shrub height			119.778	<0.001	
0.1–0.5 m	−1.130	0.446	6.434	0.011	0.323
0.6–1 m	−0.598	0.297	4.058	0.044	0.550
1.1–2 m	0.184	0.267	0.473	0.492	-
>2 m	1.997	0.353	32.040	<0.001	7.365
Shrub: first branch to ground			108.724	<0.001	
1–5 cm	−0.909	0.323	7.920	0.005	0.403
6–10 cm	−1.159	0.297	15.230	<0.001	0.314
11–20 cm	−1.520	0.258	34.792	<0.001	0.219
21–30 cm	0.421	0.206	4.187	0.041	1.524
Shrub shade			106.716	<0.001	
Little shade	0.976	0.322	9.208	0.002	2.653
Half shade	−0.374	0.254	2.161	0.142	-
Much shade	1.224	0.235	27.257	<0.001	3.402

Note: Reference categories: Tree height = “no tree”; Tree shade = “no shade”; Shrub height = “no shrub”, Shrub first branch = “0 cm”; Shrub shade = “no shade”.

On the ground surface types, 21 out of 28 surface types are positively associated with algae growth and seven types of surfaces are not statistically significant in comparison with the reference surface "main road", which has no algae habitat. The predicted odds ratio (OR) represents the probability of algae formation.

Based on the OR value of each type of ground surface, the five most significant features promoting algae growth were "concrete material", "soil mix/loose material", and "ground cover". First, the surface type "concrete ditch" appears most suited for algae formation. The surfaces related to "compacted soil" also show significant effects as the second and third influential factors. Areas constructed by the loose material made of "brick gravel" were found to be the fourth most suitable surface for algae generation. Finally, "spotty lawn" presented as the fifth best surface to grow algae compared to the reference surface.

Furthermore, the following 6th to 12th surface types increased the odds of algae growth across three different categories. These included "concrete material", "fallen leaf mulch", and "soil mix/loose material". Among the seven surface types in this group, there are four surface types ("thin sand on planting soil", "clay", "gravel sand on soil", "rock slab") pertaining to the category of "soil mix/loose material". In addition, two significant surfaces of the "fallen leaf mulch" category ("multi-layer leaf much", "single layer leaf mulch") and the surface made of "concrete" also revealed an impact on algae growth in this medium-level group.

Relatively speaking, the final nine surface types are considered least suited for algae growth in this group (OR ranged from 16.586 to 2.055). Among these, the three significant surfaces of the "brick material" category ("red brick", "timeworn permeable brick", and "newly installed permeable brick") all fall within this group. The ecological "ground cover" ("meadow" and "lawn") displays algae prohibitive effects. Similarly, the surface types of "close lightly pebbled" and "asphalt" indicate some preventive effects as hard surface materials. In comparison, there are fewer surface types ("pebble gravel sand on bare-soil" and "active planting soil") within the category of "soil mix" in this group.

Furthermore, there are seven statistically insignificant surface types, which include the surfaces of "tile", "plastic pad", "polyurethane", "thick leaf mulch", "wood", "pond", and "building top". In these cases, however, adjacency to buildings and pavilions both moderately increase algae growth.

For vegetative factors, the height and shade under trees and shrubs were tested, along with the gap between the shrub body and the ground. The results indicate that the tree factors have significant effects on algae growth. Tree height, for instance, displays a negative effect on algae formation, indicating that, overall, places covered by tree canopies are less likely to grow algae in comparison to treeless areas. However, the odds of algae growth moderately increase with more shade.

The findings for shrub factors appear to be mixed. The results show that lower shrubs (0.1–0.5 m, 0.6–1 m) reduce the odds of algae growth, respectively, by 68% and 45% in comparison to no-shrub areas. However, shrubs more than 2 m tall increase the odds of algae formation, while the shrub height of 1–1.2 m is insignificant. Additionally, for the gap between the ground and the shrub body, the findings fall into two conditions. One is that when the gap is less than 20 cm, the probability of algae is reduced by 60% to 78%. The other is that a gap greater than 20 cm promotes algae growth by 1.52 times. In terms of shrub shades, the results show that two out of three shading levels are positively associated with algae growth. The significant factors "little shade" and "much shade" promote 2.65 and 3.4 times the odds to form algae, while the shade level "half shade" is insignificant.

4. Discussion and Conclusions

This study investigated the relationships between landscaping factors and algae growth as indicators of larval breeding sites. The ground surface and plant characteristics were examined using spatial analysis to establish preventive strategies for sustainable landscape design and planning. The findings indicate that the ground surface types are especially critical to algae growth. Among the surface types, the uncovered concrete ditch structure promotes algae growth the most. The surface of compacted soil is also closely linked to algae growth, with stronger effects as compared to flat concrete surfaces.

In addition, algae growth shows an evidently strong link with soil mix/loose material, such as the surface covered by loose particles of bricks or a mix of gravel, sand, and soil. Surprisingly, a spotty lawn is also a strong promoter of algae growth, though to a lesser extent. These surfaces are capable of both water retention and absorption, hence providing humidity for the algae. The particles forming the surfaces often have rich porosity and sufficient volume to facilitate moist absorption and retention from rain or irrigation. Coupled with sunlight, these types of surfaces can easily form a microenvironment for algae habitation.

For ground types that are less conducive to algae production, "lawn" surfaces with comprehensive coverage are good for adequate algae prevention, along with asphalt, active planting soil, meadow/ecologically grown grasslands, and newly installed permeable bricks. Those surface types which showed relatively lower chances for algae growth comprise both hard surfaces ("asphalt", "new permeable brick") and soft surfaces ("lawn", "active planting soil", "meadow").

For the hard surfaces, the preventive effects of permeable bricks and asphalt surfaces are believed to operate through different mechanisms. The permeable bricks observed were mostly in the form of high-pressure bricks, which are rough, porous materials and often installed with drainage grading under the bricks. This installation method provides sufficient separation from the supply of water to stymie algae growth. In addition, as a surface effective for algae prevention, permeable bricks are widely used as paving materials in landscaping and have a variety of shapes. On the sites that were surveyed, it was found that, compared with solid permeable bricks, the hollow-frame type of bricks can aggregate a large amount of algae on the soil within the hollow space, while the grasses planted in the hollow space fail to grow successfully. Supposedly, the soil filled in the hollow space retained water and provided an environment for algae growth. It is also observed that the permeable bricks with a low frequency of treading over a long period of time showed a tendency to become an algae habitat. Therefore, when using permeable bricks, matching the bottom drainage grading will help control the breeding of the black midge. For the preventive effect of asphalt surfaces, it is possible that the installation of asphalt surfaces uses layers of impermeable material and particles on the top to isolate the ground from water absorption. However, this preventive effect may also be due to chemicals in the asphalt that are toxic to algae.

Among the soft surfaces, lawns and ecological grassland are relatively effective in blocking algae. This may be because the grasses successfully compete with the algae for soil, water, and light resources. Compared with incompletely paved lawns ("spotty lawns"), a well-covered lawn performs much better in algae reduction than its counterpart. When the coverage of lawns and ecological grassland is not sufficiently extensive, algae growth can occur on the exposed soil surface. Therefore, for grass surfaces, complete surface coverage should help to prevent the growth of algae. Another soft surface—"active planting soil"—is periodically stirred and tossed, and, in contrast to a soil surface in a fixed or compacted state, this soil displayed preventive effects. It was, in fact, the soil surface that performs the best with blocking effects.

The research results show that the algae growth around and under shelter structures is relatively vigorous. The area around the structure is often surrounded by drainage ditches with no cover and receives rain water drips from the edges of buildings or pavilions. These conditions may create environments conducive to algae growth. Therefore, algae can be contained by ensuring proper drainage of the surface adjacent to buildings, decreasing sunlight with ditch covers, and increasing competition by planting groundcovers.

With regard to vegetative factors, the effects are much lower compared to surface types. The preventive effects of differing tree heights are fairly consistent regardless of height. Additionally, more tree shade results in a moderate increase in algae. This may be because the decrease in direct sunlight affects the habitat temperature, humidity, and the degree of water evaporation, creating a better microclimate for algae development. However, algae can adapt to environmental conditions in a wide range, so a combined approach might be necessary for algae prevention.

Among the shrub factors, the more significant finding is that, when the shrub height is low and close to the ground, it shows that algae growth is inhibited. However, when the shrub is taller and the position of its first branch is more than 20 cm above the ground, there are more traces of algae growth. This indicates that the growth of algae is more sensitive to near-ground environmental conditions, and this may be a useful focus during landscape design.

With regard to the study's limitations, it should be noted that tested landscape features were restricted to the composition and material installed in the study sites. Future studies should include more diverse factors in constructed landscape environments to better understand the interactions between algae generation and the landscape compositions. Such studies should also consider the effects based on the combination of variables to understand specific landscape conditions determined by multiple landscape elements. This study used observational methods to identify algae by their appearance and color, but bio-examination methods to identify species will be more effective to better understand the relationship between landscape planning and the algae breeding site of the bloodsucking midge.

Several practical implications can be drawn from this study.

First, the formation of larval breeding sites is closely associated with the ground surface and shading levels. The size of the midge breeding sites can be small, spottily distributed, and numerous. With pavement options, efficient drainage is crucial in installation for reducing the moisture content needed by breeding sites.

Second, since algae prefer the humidity and sunlight conditions of concrete ditches, landscape designers should place movable covers on concrete ditches to block sunlight while allowing maintenance.

Third, compacted soil and surfaces made of loose material, such as pebbles, gravel, and brick particles, are more likely to cause algae to adhere and grow. Thus, landscape designers should consider ground surface alternatives, such as ground cover, lawn, wild grasses, or permeable blocks with proper drainage.

Fourth, when shrubs are being planted, it should be a species that grows densely and leaves small gaps from the ground to reduce the penetration of oblique sunlight into the space under the shrubs to reduce algae accumulation.

Fifth, compared with other factors, the height of trees and shrubs is less impactful on algae growth. Therefore, the height of plants in a landscape can be flexible.

Landscape settings closely relate to the psychosocial, physical, and economic aspects in our society. This study provides empirical information on the fundamental factors in landscape design related to the habitat formation of bloodsucking midges. The selection options and practical implications may provide a sustainable and healthy method, instead of pesticide use, to mitigate the bloodsucking midge population in landscape spaces.

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