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Determining the number and distribution of *Firmiana Danxiaensis*, a rare and endangered plant species in Danxiashan, South China, using DEM data and UAV technology

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Abstract. *Firmiana danxiaensis*, a rare and endangered plant species in Danxiashan, South China, belongs to Sterculiaceae family. The central Danxiashan covering an area of 10.6 km² was selected as a case study. The location data of *F. danxiaensis* was collected by field work, and the environmental variables (slope, aspect, and elevation) were generated from DEM data of 1m resolution, while their images were collected by unmanned aerial vehicle (UAV) in revealing the relationships between the micro-landforms and their spatial distribution. Three spatial analysis modules of ArcGIS10.0, including the Raster Surface-Contour List, slope, and aspect functions were used to extract from the DEM data of 1m resolution which were superimposed on the remotely-sensed photo data and transferred onto maps for the purpose of visualizations. The visualized maps indicated that there were no more than 1000 *F. danxiaensis* in the case study area. They are mainly distributed along sheer Danxia cliffs, with slopes above 30° and elevation ranges from 100-300m. Also these cliffs have with vertical joints or horizontal bedding, and some drought tolerant plants, such as *Osteomeles subrotunda*, *Lycoris aurea*, and *Selaginella tamariscina* were usually found nearby. The main conclusions are as follows: 1 The special Danxia landforms provided the key survival space for *F. danxiaensis* which is a kind of drought tolerant plant, growing mainly along Danxia cliffs with joints or beddings of thin barren soils. 2 According to the rules discussed above, *F. danxiaensis* is presumably distributed outside of the case area with the similar sheer cliff micro-landform environments in Danxia landforms. 3 Our research here may provide a proof of concept that UAVs may provide a low cost and accurate method in fast conducting surveys of data.

1. Introduction

Danxiashan, one of the six World Nature Heritage sites of “China Danxia,” has special rare and endangered vegetation such as *Firmiana danxiaensis* (Figure 1-a,b,c,d,e); *Danxiaorchis singchiana* (Orchidaceae)(Figure 1-f); *Spiradiclis danxiashanensis*(Rubiaceae)(Figure 1-g); *Viola hybanthoides* (Violaceae)(Figure 1-h); and *Chiritopsis danxiaensis* (Gesneriaceae) (Figure 1-i). Because of its



geographic position and beautiful Danxia landforms, more and more studiers and visitors from all over the world are attracted every year.

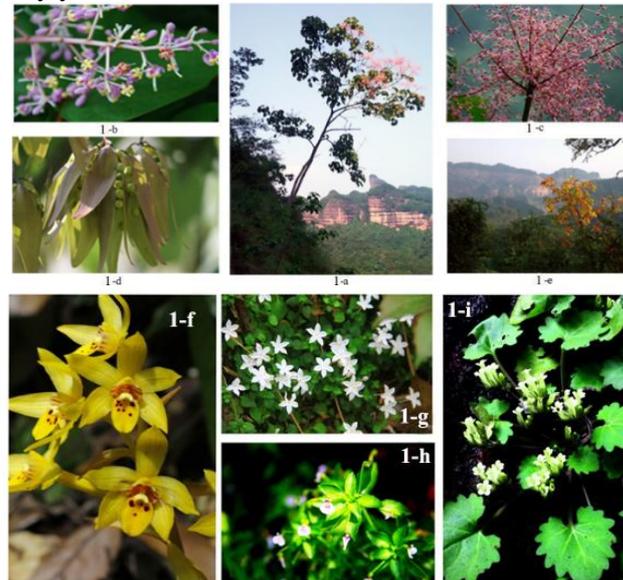


Figure 1. Part special plants in Danxiashan

These rare and endangered plants are the common wealth of all mankind which have great significance in revealing the origin of the species, system evolution, genetic breeding, reproductive ecology, as well as understanding of the ancient geology, paleo-climate and so on[1,2]. The potential extinction of the species looms unless we strengthen efforts to protect them, otherwise the loss would be enormous and irreparable[3]. Take *F. danxiaensis* as an example, it is listed at the highest grade of critical endangered (CR) plants in the first volume of “The China Species Red List”[4], as well as the Second National Grade Protection of Wild Plants which was announced by the State Council and enacted by the State Forestry Administration (SFA) and the Ministry of Agriculture. It is an ornamental plant with a beautiful configuration (Figure 1-a) and gorgeous purple flowers (Figure 1-b, c) that bloom from May through June. It has 15 female anthers and spherical, yellowish-brown subglobose seeds (Figure 1-d). Its barks are dark brown, cylindrical, and glabrous. Its tender branches are green and cylindrical. Its leaves are suborbicular, thin, leathery, rounded at the apex, and cordate at the base. The best period to perform field investigations to identify this plant is at the end of October while its leaves are turning yellow (Figure 1-e).

There have been specific research accomplishments concerning the *F. danxiaensis* species of Sterculiaceae in China when it was first identified by Xu in 1987[5]. Xu and Xu[6,7] studied the distribution of Sterculiaceae plants internationally and in China. Luo, et al.[8] analyzed the geographic elements of the plant species’ communities with extremely small populations of *F. danxiaensis*. There were some researches concerning the genetic diversity and microsatellite markers in the transcriptome of *F. danxiaensis* [9,10]. The main feature of the research site belongs to Danxia landforms. There are abundant studies on lithology, spatial distribution, and mountain peak and valley ecological effects in the field of Danxia landforms[11-16].

However, little research has been done on the relationships between Danxia landforms and plants, especially the quantity and spatial distribution of *F. danxiaensis* within their main protection red lines by now. So it is very difficult to protect them for the purposes of science and posterity. As UAVs may provide a low cost and accurate method of conducting surveys in getting the data of the number of *F. danxiaensis*, the rare and endangered plant in Danxiashan, summarizing their spatial distribution in

regards to the features of micro-landforms (slope, aspect, elevation), and establishing protection red-lines in their area of concentration.

In order to get the number and the spatial distributions of *F. danxiaensis* in the research area (Figure 2), our research team investigated the location data and the environmental variables (slope, aspect, and elevation) and collected Digital Elevation Model (DEM) data and digital photos by field investigations and UAV.

2. Description of the study area

Danxia landforms were named after the study area Danxiashan of Guangdong Province which is one of the world natural heritage sites of “China Danxia”. Danxiashan is located northeast of the Shaoguan City, Guangdong Province. Its longitude and latitude range from 113°36'25"E -113°47'53"E, and 24°51'48"N-25°04'12"N. The core area of Danxiashan is 168 km² with a buffer area of 124 (total 292) km². Our case study area is in the range of the longitude between 113°43'20"E -113°45'47"E, and the latitude between 25°1'10"N -25°02'57"N and an altitude between 68-402m which consists of three parts of Baozhufeng, Hailuofeng, and Zhanglaofeng covering an area of 10.6km² approximately(Figure 2).

The study area is in the monsoon humid climate in the transition from the middle subtropics to the south subtropical zone. The annual average temperature is 19.7°C, the average temperature in January is about 9.3°C, and the average temperature in July is about 28.4°C. The annual average rainfall is 1715mm. The name of the river in the the study area is Jinjiang, it flows from northeast to the southwest (Figure 2).

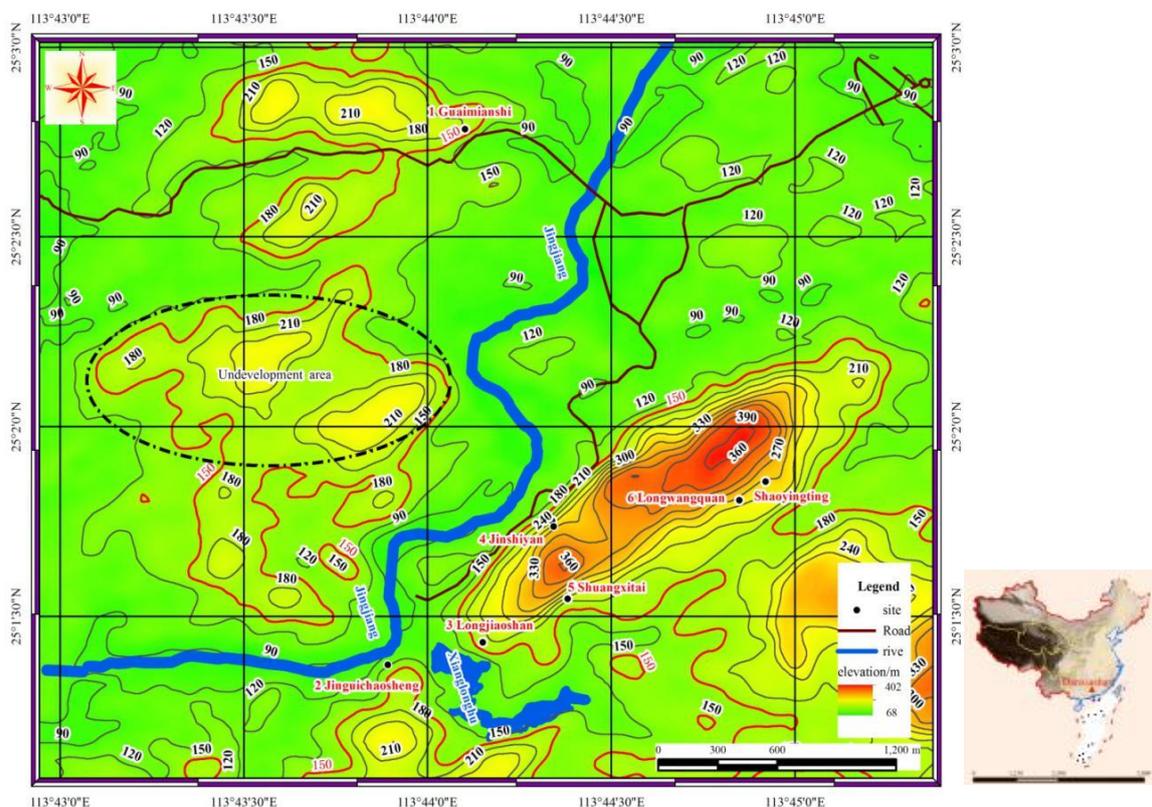


Figure 2. The location and scope of the study area at Danxiashan.

3. Materials and methods

Quantifying the distribution and abundance of plants is of fundamental importance to plant ecology[17]. UAV technology has been used for mapping, quantifying and monitoring plant species[18]. The goal in this study is to use this UAV technology to find the number and the spatial distributions of *F. danxiaensis*.

Firmiana danxiaensis is a good fit for automated identification from UAV imagery due to its leaf colouration making it stand out. The number of *F. danxiaensis* we counted mainly through macroscopic field investigations, while the location data of *F. danxiaensis* were mainly acquired from UAV imagery using computer technology. Our research here may provide a proof of concept to present UAVs as a low cost and accurate method of fast conducting surveys of the other areas in the next deep research.

3.1. Macroscopic field investigations to acquire the number of *F. danxiaensis*

In order to get the quantity and spatial distribution of *F. danxiaensis*, our research team performed field investigations on the characteristics of the vegetation community, took pictures (more than 2,650), and GPS positions (more than 180) at Danxiashan in January, June, and October, 2016. At present, 772 *F. danxiaensis* plants are counted in the case sites (Table 1).

Table 1. The number and position of *Firmiana danxiaensis* in the case area.

order	site	Quantity (total: 772)	order	site	Quantity (total: 772)
1	Guaimianya nearby	70	13	Fuyingxia nearby	5
2	Entrance of Yangyuanshi	20	14	Both sides of cliffs of Shuangxitai	60
3	The west joints and cliffs at the entrance of Yangyuanshi	23	15	Cliff of Longwangquan-Shaoyingting	30
4	The gate of Tengsheao	3	16	Cliff of Duoshi	30
5	The west cliff of Shiziyuan	15	17	The entrance of Zhanglaofeng	30
6	Cliff below Xuanjitai	20	18	The Batou of Xianglonghu nearby	10
7	Fanghechi nearby	10	19	Cliffs of Longjiaoshan	120
8	The bank of Yangyuanshi	7	20	Cliffs of Jinguichaosheng	70
9	West cliff of Baozhufeng and nearby	93	21	Guangmaoshi nearby	4
10	The cliff by the site 1	71	22	The east cliffs of Xianglonghu	10
11	East cliff to Zhanglaofeng	40	23	Xiaoshunling	8
12	Yufengting nearby	6	24	Yinguanshi nearby	28

3.2. Imagery data acquired from UAV

A salient feature of *F. danxiaensis* was its yellow leaves in October, which was noticeably different from adjacent plants. The imageries of *F. danxiaensis* which got by low altitude UAV research had great help in identifying them from different angles (from head, face, left, and right) in the maximum discrimination period from 26-29th, October, 2017, by flying a UAV (Figure 3, Table 2). And it is needed for quantitative analysis of the spatial distribution of the micro landform environmental parameters in relation to *F. danxiaensis*.

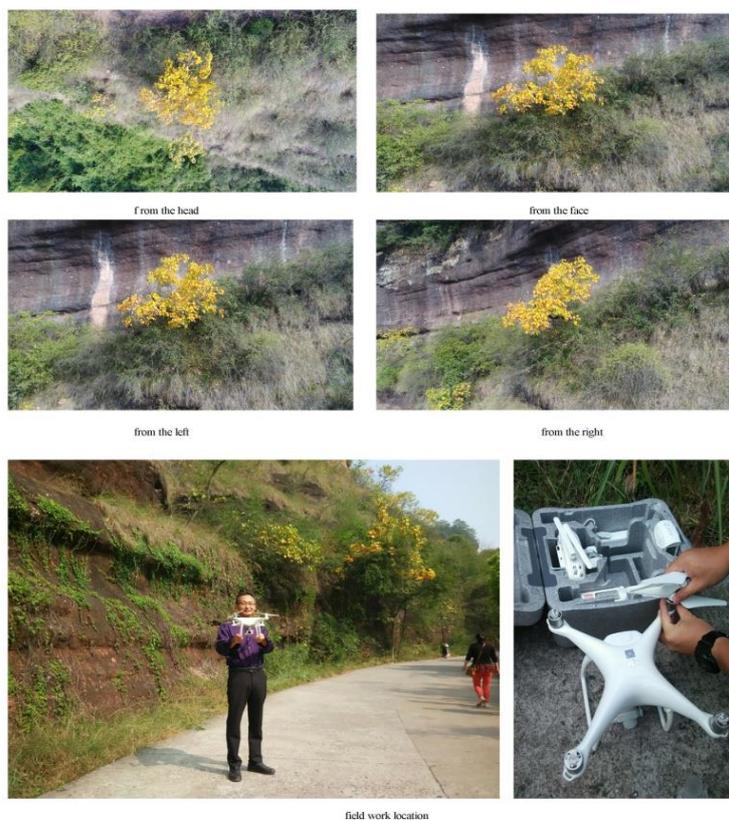


Figure 3. Single *Firmiana danxiaensis* at the cliff which observed from different angles by UAV.

The UAV flight was controlled by an autopilot program (Figure 4). The flight altitude was 290.3m which is above the highest-level of the flight area, and the speed was 9.6m/s. Equal distance photos were taken with the Phantom 3 Standard Camera, its resolution is 12.6 CM/PX and the size of one photo is 190.04cm x 108.59cm. There was a 75% overlap from fore-and-aft sections of each photo. Some important objects were captured from different angles by manually flying the UAV through the research area (Figure. 3-5).

Table 2. UAV technical parameters (Brand: DJI, made in Shengzhen, China).

parameter	data	Parameter	data
Weight (including batteries and flanks)	1388g	The maximum rotating angular speed	150-250 %s
Wheelbase	350mm	The maximum flying elevation	6000m
The maximum speed upward	5-6m/s	The maximum flying time	30 minutes
The maximum speed downward	3-4m/s	The temperature of working environment	0-40 °C
The maximum level speed	50-72km/h	Modules of satellite position	GPS/GLONASS
The maximum aslant angles	25-42 °	Hovering accuracy	0.1-1.5m

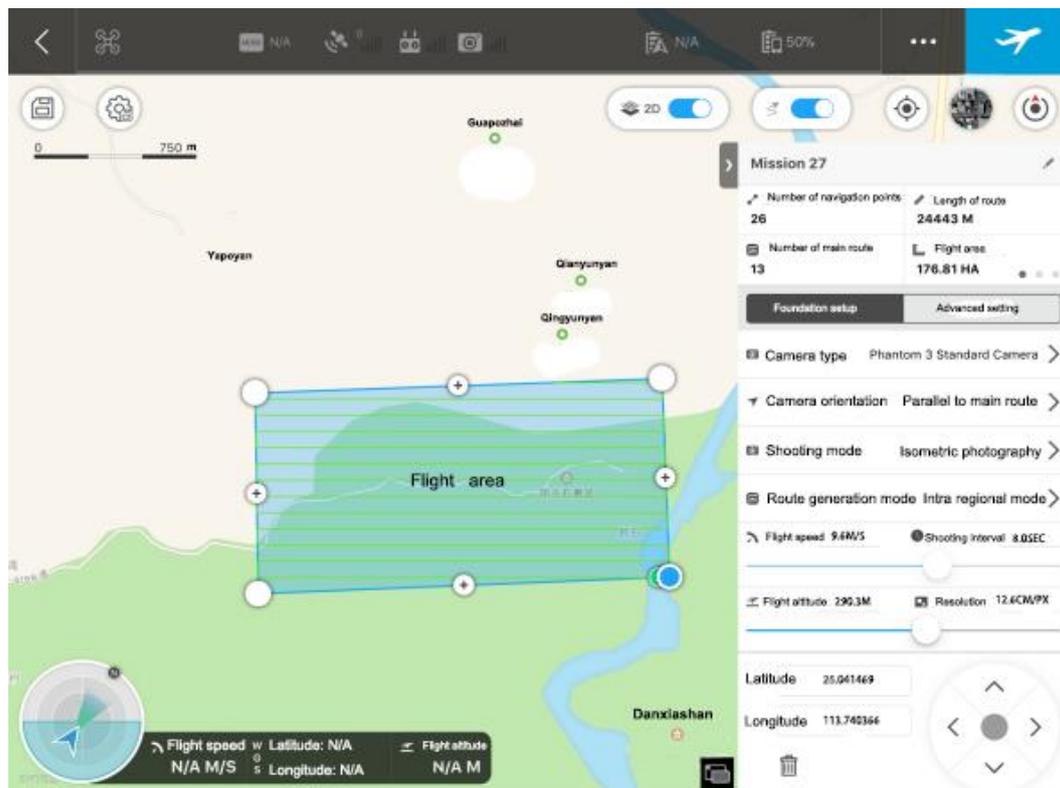


Figure 4. The scope of the flight area.



Figure 5. Control points while photographing Shiziyan via UAV.

3.3. Data visualization

Data Visualization is the theory, method and technology of using computer graphics and image processing to transmit data into graphics or images on the screen[19]. The main characteristics of data visualization technology are interactivity, multidimensionality, and visibility. It has been successfully applied in the fields of medicine, geology, and meteorology[20]. After an adequate amount of photos were collected via UAV, it became a complex task to fit them together (Figure 6 and 7), as the amount of data to work with are quite large. This task was accomplished, in December, 2017, by the Tuyao Information Science and Technology Remote Sense Company of Guangzhou, using the software Photoscan. This company also provided the DEM data (Figure 8) of the research site. These data were superimposed onto the photo data (Figure 9), three spatial analysis modules of ArcGIS10.0 of Raster Surface-Contour List, slope, and aspect functions were used to extract the accurate information lastly.



Figure 6. One image which taken by UAV.

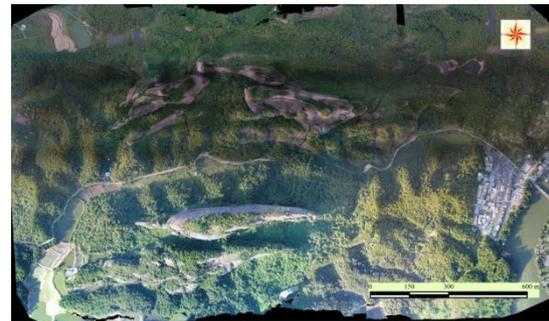


Figure 7. The image of Ynagyuanshan-Shiziyuan mosaic through Photoscan in the research area

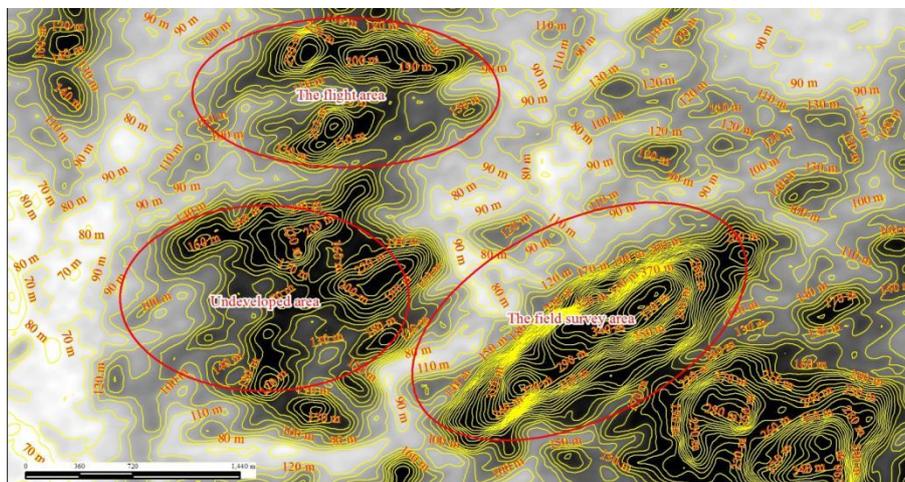


Figure 8. The DEM data of the study area, used to generate contour lines (three red highlight circles: the flight area which combining with Figure 7 may generate Figure 8; field survey; and unknown area respectively) .

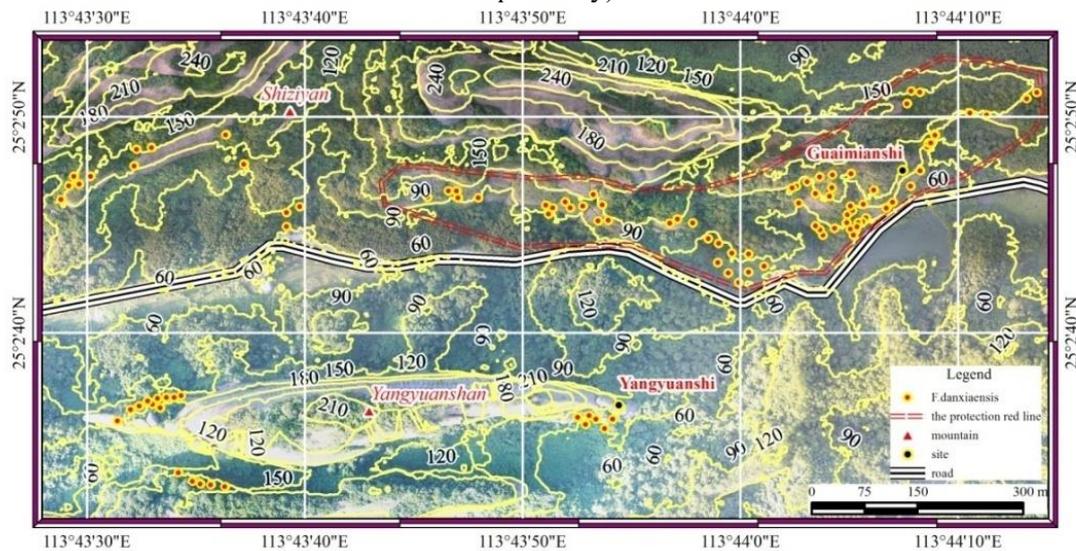


Figure 9. The distribution of *Firmiana danxiaensis* in Yangyuanshan-Shiziyuan which obtained by UAV imagery added on DEM data.

4. Analysis and discussion

4.1. Analysis of the relationship between distribution of *F. danxiaensis* and altitude

From an investigation of vegetation at Danxiashan in January, 2016, it becomes clear that *F. danxiaensis* is sparsely distributed along the peaks and foothills. At Danxia cliffs, however, *F. danxiaensis* is relatively widely dispersed. This is likely due to tourism development around the summit and foothill areas, and the fact that few plants could survive on Danxia cliffs. But the Danxia cliffs provide a relatively favourable space for the survival and development of *F. danxiaensis*. It was found that the distributed range of the altitude of *F. danxiaensis* is from 100-300m. The dense zone of *F. danxiaensis* is about 180m in Guaimianya at the southeast part of Shiziyan, the highest altitude of *F. danxiaensis* is generally not more than 200m in the case areas (Figure 10).

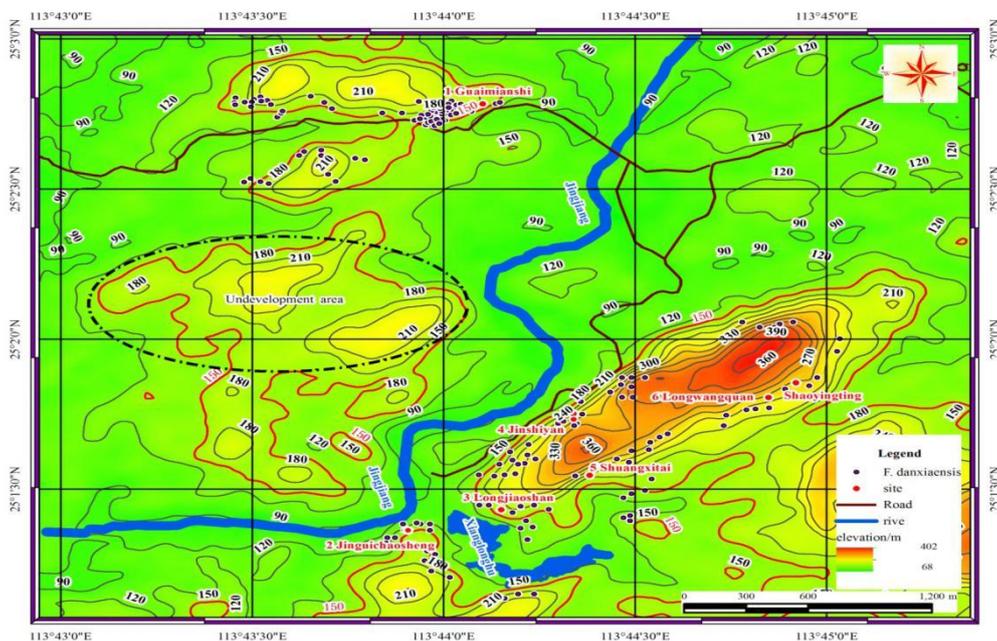


Figure 10. The distribution of *Firmiana danxiaensis* in the research areas.

4.2. Analysis of the relationship between distribution of *F. danxiaensis* and slope, aspect

Firmiana danxiaensis in the case study area has a greater distribution along cliffs steeper than 30°, especially cliffs at an elevation of 180m or so with beddings and joints. We also found that *F. danxiaensis* is concentrated at the south-southeast slopes of Shiziyan, with a small range of dispersion along the northwest slopes of Yuanguyanshan. The facts above show that aspect is not the most important micro landform factor restricting the spatial distribution of *F. danxiaensis* while the special micro landform of cliffs provides the key survival space for *F. danxiaensis*.

According to analysis on the *F. danxiaensis* spatial distribution of elevation, slope, and aspect, we may speculate that *F. danxiaensis* is presumably distributed outside of the case area of Danxiashan and other sites of Danxia landforms within not too long distance with the similar micro landforms of sheer cliffs. Fact needed to be verified urgently for the next step deep research.

4.3. Controlling factors of *F. danxiaensis* spatial distribution

4.3.1. The special position of Danxiashan gestates rare and endangered plants, including *F. danxiaensis*

Danxiashan is located in the middle of the Southern Nanling Mountains, which act as a natural boundary for local vegetation between the north and south. It is the northern boundary for many

tropical species and the southern boundary for many warm temperate species. Concerning Chinese plant division, Danxiashan is located in the northern section of the “Southern China area” of the “China-Japan forest plant sub-region” (He, *et al.*[3] 1991). The vegetation is rich and varied in Danxiashan including *F. danxiaensis*, which makes it an important source for plant species and genes (Ao and He.[1], 1992).

4.3.2. The special Danxia landforms provide key survival space for F. danxiaensis One of the significant features of Danxia landforms[21-23] are red sandstones and conglomerates with abrupt cliffs where few plants can survive because of a lack of water and strong sunshine on cloudless days. But *F. danxiaensis* is relatively drought tolerant, growing mainly along Danxia cliffs with joints or beddings with thin barren soils. Notably, within the distribution zone of *F. danxiaensis*, plants such as *Osteomeles subrotunda*, *Lycoris aurea*, *Selaginella tamariscina* can always be found nearby. They have menial root development, which fully reflects plant adaptation under the constraints of survival in similar micro geomorphic environments. In order to adapt to the environment, *F. danxiaensis* has straight trunks, an especially sophisticated root system, which can not only repair itself in growth and development, but also take in sunlight and maximize the absorption of water. These performance advantages allow the plant to survive along the relatively barren cliffs.

4.3.3. The micro-landforms (slope, aspect, elevation) restrict the growth and development of F. danxiaensis

The characteristics of the aspect, slope, and elevation of *F. danxiaensis* are analyzed above from the case area. We have found the fact that *F. danxiaensis* is relatively concentrated along cliffs above 30°, especially cliffs at an elevation of 100-300m with beddings and joints. If we enlarge the research area for the next step, the scopes of slope and elevation would become small and big respectively. However, the micro landform of slope, aspect, and elevation, especially slope, affect and even restrict the growth and development of *F. danxiaensis* in the case area.

5. Conclusions and prospects

5.1. The micro-landforms of aspect, slope, and altitude, especially the Danxia slopes, provide a key survival space for the rare and endangered species of *F. danxiaensis* which is mainly concentrated on Danxia cliffs with vertical joints or horizontal beddings at an altitude of 100-300m and above 30° slopes of relatively barren soils. Many drought-tolerant species, such as *O. subrotunda*, *L. aurea*, and *S. tamariscina* can always be found nearby.

5.2. Our research combined field investigations with low altitude UAV collected data, information recognition, and information extraction technology. In the seasonal variation of vegetation, the salient features of *F. danxiaensis* are purple flowers in June, especially yellow leaves at the end of October, gives *F. danxiaensis* a notable physical differences from adjacent plants, which is a good time with the UAV assistance in identification.

5.3. We may speculate that *F. danxiaensis* is also distributed within similar micro-landforms of Danxia cliffs in other undeveloped areas of Danxiashan and Danxia landforms outside of Danxiashan with not too long distance and similar micro landforms of sheer cliffs. The actual situation needs to be further investigated and verified.

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