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Using an optimization algorithm to establish a network of video surveillance for the protection of Golden Camellia

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ABSTRACT

The natural environment is facing increasing human disturbance. Many species of flora are extinct or endangered. To improve the efficiency of ecological management and monitoring, this study proposed to establish a video monitoring network to protect a world-famous rare flora: Golden Camellia, in Fangcheng nature reserve, Guangxi Province, China. Based on the model of LSCP (location set covering problem), we attempted to establish full monitoring coverage of camellias while minimizing the number of video cameras. The model was solved by integer programming. In case of multiple solutions, this study proposed two additional criteria, maximize monitoring area and maximize overlapping count, to eliminate suboptimal solutions. Both of the two optimal solutions included 80 cameras covering a monitoring area of over 55 km^2. Together, these cameras are able to monitor 97.2% of golden camellia in the reserve. The findings of this study suggest that this location optimization model can be used to improve the conservation effectiveness of rare species.

1. Introduction

Since 1900, we are experiencing much higher species extinction rates than the background rate (Pimm et al., 2014). Although much attention over species extinction focuses at the global scale, most biodiversity benefits actually take place at the local level (Blanca et al., 1998; Moreno Saiz et al., 2003; Volis, 2016; Zhang et al., 2015). The conservation of local populations is the only way to ensure genetic diversity that is critical for a species' long-term survival. The establishment of natural reserves is often viewed as the cornerstone of biodiversity conservation (Haight et al., 2000; McDonnell et al., 2002). It is recognized that building nature reserves is the most effective way of protecting biodiversity (Naughton-Treves et al., 2005).

However, most of the current nature reserves are not functioning as originally envisioned due to the increasing ecological pressures such as fires, floods, insect pests, and human activities (Hansen and Ruth, 2007). Extensive human activities, such as ongoing agricultural and tourism expansion and illegal resource extraction are leading to habitat loss and fragmentation that jeopardizes the survival of some valuable plant species and other important nature resources (Gandiwa et al., 2013; Yonariza and Webb, 2007). Compared to the developed countries, the importance of nature conservation in the developing countries is more significant. Due to rapid population growth and the environmental degradation, biodiversity and natural resources in the developing countries are facing increasing pressures. Taking China as an example, the Chinese flora, despite their unique position in global plant diversity, is under severe threat by anthropogenic pressures (Volis, 2016). National and provincial nature reserves in China cover only 27.5% of the distribution areas of the threatened plant species (Zhang et al., 2015). Many reserves of high species abundance suffer increasing human activities, with additional issues of staff shortage and inadequate management facilities. Especially, the nature reserves in mountainous areas are often faced with lack of real-time and reliable information. In addition, the remoteness and logistical challenges in mountainous areas further exacerbate the management difficulty.

This study aims to examine the protection of an endangered flora species — Golden Camellia in Guangxi province, China, through establishing an efficient network of video surveillance cameras. In dealing with the problem of locating a minimum number of viewpoints on an irregular topographic terrain to observe the entire surface, Goodchild and Lee (1989) predicted that similar problems might arise in the context of installing security surveillance cameras, fire towers and observation posts. The technology of video surveillance has been widely used in the management of nature resources because of its merit of consistent, reliable and constant monitoring. Video surveillance is also a non-intrusive way of monitoring plant species. However, the video

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monitoring systems have more often been employed in monitoring forest fire (Badri et al., 1998; Bao et al., 2015; Murray, 2013) than in the management of rare or endangered species. We believe that the establishment of video surveillance in nature reserves could greatly contribute to the early detection and correction of human disturbance.

Similar to the fire monitoring system, determination of the optimal locations of monitoring points is critical in the efficient and effective protection of plant species. This is because the selection of monitoring points is directly associated with the construction cost of the monitoring system and the monitoring coverage of rare species. Methodologically, this location problem is a natural extension of the classic location set covering problem (LSCP). LSCP is a combinatorial optimization problem that is aimed at minimizing the total cost while satisfying a set of specific requirements such as full coverage, maximal coverage and so on. Hakimi (1965) was the earliest study to consider the set covering problem; while Toregas et al. (1971) was the first to exploit the linear programming method to develop a mathematical covering model for the emergency facility-location problem. The applications LSCP have also been expanded to other problems such as the location of hospitals, libraries, schools, post offices, parks, military installations, banks, shopping centers and waste-disposal facilities (Farahani et al., 2012; Schilling et al., 1993). To the best of our knowledge, this study is the first to consider the optimal placement of video cameras in the context of species conservation.

2. Background

Golden camellia (*Camellia chrysantha* or *Camellia nitidissima*) is a species of plant in the theaceae family. It is a world-famous garden plant because of its large size, golden-yellow colour and transparent waxy appearance of its flowers (Fig. 1). Among hundreds of species of theaceae family, golden camellia is the only species with yellow flowers, rather than white flowers or safflower. It is thus honored as “the queen of camellia” and “the giant panda of the vegetable kingdom” (Liang, 1993). According to Global Trees Campaign (2016), as a medicinal product, dried wild golden camellia flowers are priced at more than 10,000 yuan (about US$1607) per kilogram.

Due to the increasing anthropogenic pressure, deforestation and destructive collection of seedlings the natural population of golden camellia has declined greatly in recent decades. It is now classified as a first grade endangered plant species in China and is recognized as vulnerable in the IUCN red list of threatened species (International Union for Conservation of Nature and Natural Resources, 2000).

Golden Camellia is distributed in a narrow region of Guangxi province, China, extending into northern Vietnam. Only two golden camellia habitats have been found in Guangxi province. One is in Longzhou County; and the other is in Fangcheng City (Su and Mo, 1988). In 1984, Fangcheng Golden Camellia Nature Reserve was established. The reserve is situated approximately 20 km west of Fangcheng city and approximately 120 km south of provincial capital Nanning (Fig. 2), comprising an area of 92.89 km^2. The reserve is located in a northern tropical monsoon zone that experiences abundant rainfall, with an annual rainfall of 2900 mm. Fangcheng reserve is mountainous, with a peak of 940 m. As shown in fig. 2, the reserve is northeast-southwest oriented. Golden Camellia is unevenly distributed across this reserve, covering an area of 6.9 km^2. Within the reserve, there are about 2300 residents living in eight villages. In contrast, there are only 17 staff including five managers managing the entire reserve. Because the current management actions are simply based on access restrictions, Golden Camellia has always been facing the risk of being unlawfully picked and illegally purchased. This undoubtedly poses a severe challenge to the management.

3. Methodology

3.1. Viewshed analysis

The viewshed of the monitoring site is the crucial factor that must be considered when setting up video monitoring points on an undulating terrain. A viewshed is an area that is visible from the monitoring point. In this study, we assumed that a video camera can monitor a 360-degree direction. The viewshed analysis is a routine function of GIS and has been used in a wide range of applications (Kim et al., 2004). Similar to the context of this study, Camp et al. (1997) developed a management scheme that considers buffer zones incorporating the viewshed from each golden eagle nest in Canyon Preserve, Colorado, to reduce human activities that can potentially disturb eagles.

In addressing the optimization of visibility coverage problem, a major concern is the selection of candidate viewpoints. Goodchild and Lee (1989) used TIN (triangulated irregular network) to represent the real terrain surface; and the vertices of TIN were used as candidate viewpoints. An alternative is to generate a set of viewpoints on a lattice that covers the study area, using some criteria based on raster DEM (Digital Elevation Model). Although one might intuitively expect the highest elevation points to have the best visibility, Franklin and Ray (1994) actually found a correlation coefficient of only 0.12 between visibility and elevation. Therefore it is difficult to predict visibility with a high degree of accuracy simply by considering local properties of the surface, such as elevation and topographic feature type (Kim et al.,

Fig. 1. Golden Camellia (1: grove; 2, 3: flower).