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Application of digital terrain model in identifying potential conservation area (PCAs) of subtropical forest in Okinawa, Japan

N J N Jemali^{1,*}, S Masami² and A Z Azita³

¹Faculty of Earth Science, Universiti Malaysia Kelantan, 17600 Kelantan, Malaysia

²Faculty of Agriculture, University of the Ryukyus, 903-0213Okinawa, Japan

³Faculty of Forestry and Environment, Universiti Putra Malaysia, 43400 Selangor, Malaysia

*E-mail: janatunnaim@umk.edu.my

Abstract. Conserving the Northern forest of Okinawa Main Island is very crucial and the selection of significant areas to be protected is a complex and challenging process. The altitudinal gradients provide ideal settings to determine priority area for conservation hence improving our understanding of species richness and distribution pattern. The study sought to identify potential conservation areas (PCAs) in the subtropical forest of Okinawa Island based on the Digital Terrain Model (DTM). Different elevation levels range from were overlaid with forestland owner boundary data, vegetation, protected parks and accessible forest road. Results showed that the available PCAs decreased with an increase of elevation gradient. Protected sites require a small area as possible to allow competing demands for development and other human activities. Considering the influence of the qualitative factors for site selection, the middle-peak elevation region in the study area was chosen as the priority area for protection and conservation sites. This finding was also compared to the preceding studies which influenced the diversity of flora, fauna, climate, and geographical factors at different altitudinal levels.

1. Introduction

In February 2019, the Japanese Ministry of the Environment submitted a nomination of four areas in the Ryukyu archipelago for UNESCO World Natural Heritage status which include the Northern Part of Okinawa Island. The subtropical forest in the Northern part of Okinawa Island is very valuable for Okinawan people. It consists of diverse flora and fauna including endangered species as well as having aesthetic value. In this area, strategic management is required as the forest is used for social, environmental, and economic development. To satisfy public demand for various forest usage is a complex and challenging process, especially in selecting a suitable conservation priority area. Forest zonation is suggested to be an influential tool to delineate potential priority conservation areas. By dividing the forest area into several zones concerning the priority uses, this management system was effectively reviewed [1,2].

Okinawa is a small island, yet it is a very significant area for biodiversity conservation. Conserving the whole Okinawa forest area is impossible due to the multiple forests uses especially for communities that utilise the forests for a living. On the other hand, evaluating the Potential Conservation Areas (PCAs) in this subtropical forest area should consider many factors. It includes



forest ownership, area availability, water resource area, forest access road, forest vegetation, protected prefectural parks, and bird conservation areas. Previous studies paid little attention to the zonation function in the forest management system, defining practical parameters for conservation site selection and keep a balance between forest conservation and utilization. To tackle this issue, a forest zonal scheme based on a digital terrain model was used to describe the best site selection for conservation priority of this area. Besides, the quality and quantity factors at the selected PCAs were also overlaid to further interpret the results.

2. Materials and Method

2.1. Study area

The study was conducted in the subtropical forest in the Northern part of Okinawa Main Island (Figure 1). The area is characterised by a subtropical climate with annual precipitation and an average temperature of 2,300 mm and 22°C, respectively. There are three neighboring villages located in the study area namely Kunigami, Ogimi, and Higashi with an area of 19,314 ha, 4,609.4 ha, and 5,973.9 ha, respectively. The peak altitude was located at the Kunigami village with a maximum elevation of 502 m above sea level (a.s.l). Broadleaved trees particularly *Castanopsis sieboldii* is a prevailing tree species with mean tree height and diameter at breast height (dbh) of 7.2 m and 15.1 cm, respectively [3]. The oldest stand aged 80 years old. Strong winds with intense rainfall caused by typhoons are frequently hit the area between June and October.

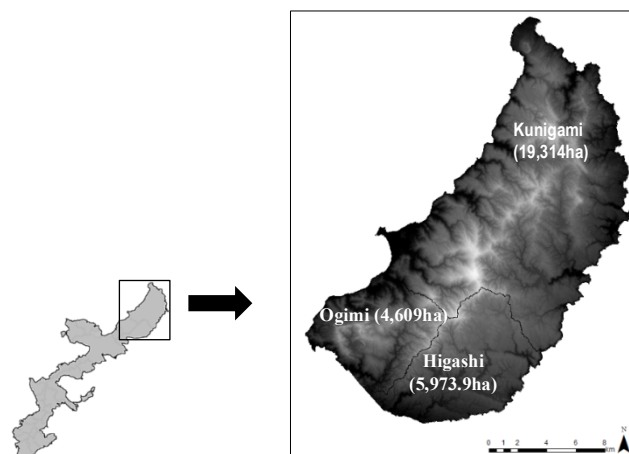


Figure 1. Study site focused at the Northern part of Okinawa Main Island.

2.2. Material and methods

Elevation is the fundamental input to create terrain data. A single band raster dataset of Digital Terrain Model (DTM) with 10x10m resolution acquired from the Geospatial Information Authority of Japan was fully utilised in this study. The data covers an area of 30,000 ha. The pre-processing of the terrain data was applied before image filtering using a 5x5 low pass filter was applied to the data to reduce the jagged effect that causes problems when identifying topographic features and minimize the noise of the data. Then, the kriging interpolation method to fill holes that represent the no-data pixel of the terrain data was applied [4]. From the DTM data, secondary products of contour lines, topographic features, channels, and flow directions were produced using spatial analysis and hydrology tools in ArcGIS v10.0. Contour lines with 50 m intervals were delineated from the DTM data. Elevation data were then categorised into three levels of low (<150 m), intermediate (150 to 300 m), and high (>300 m) group for further analysis.

The vegetation data employed in this study was originated from the estimation of tree height which was calculated based on Digital Canopy Height Model (DCHM). It was derived from the subtraction of the Digital Terrain Model (DTM) from the Digital Surface Model (DSM) values [5,6]. Besides the terrain data, supporting data include boundary information of forest landowners, location of forest protected areas, and forest road data adopted from various authorities were utilised in this study. The supporting data were overlaid and the influence of each factor to the elevation gradient was analysed to choose the ideal PCAs in Okinawa forest. Location data were in a similar projection format of UTM Zone 52N, datum JGD 2000 for a standard area calculation. Besides that, the PCAs in selected elevation gradients were also compared with the forest management planning map designed by the Department of Agriculture, Forestry and Fisheries (DAFF) of Okinawa Prefecture.

3. Results and discussion

The DTM analysis disclosed the declining of total PCAs in increasing elevation degree (Figure 2). Elevation was then categorised into 3 classes to ease the interpretation. The low category of elevation (< 150m a.s.l) suggests a huge number of area to conserve which included most of the settlement areas and agricultural lands. Meanwhile, in high elevation category (>300m a.s.l) only a small number of PCAs were included. In this category, PCAs appeared to have several patches of separate forest regions. The intermediate elevation category which ranged from 150 to 300m a.s.l encompasses the optimum PCAs for consideration. The areas were comprehended and could link as a corridor that connects between the forests in the different villages (Figure 3).

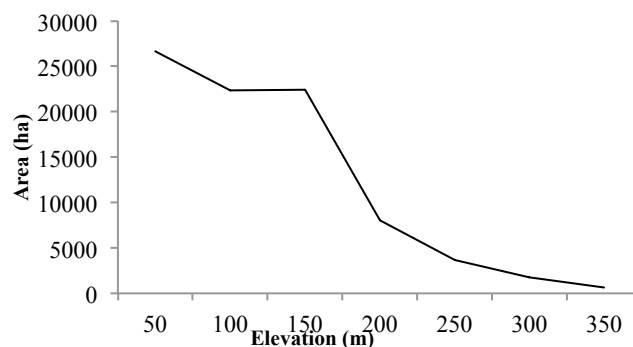


Figure 2. Area availability for PCAs at different elevation gradients.

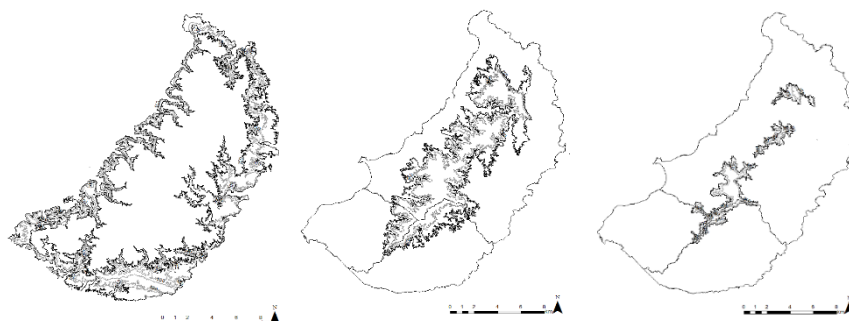


Figure 3. The proportion of PCAs from three categories of elevation level.
From left: low intermediate and high elevation categories

Conservation sites require areas that are neither too big nor too small. If the area selected for protection is too big, it may cause a huge obstacle to the community that depends mainly on the forest for a living such as the prohibition of timber production that restricts the source of income. If the area

is too small, it is unsatisfactory in providing a habitat for wildlife and vegetation conservation. An intermediate level at the middle peak elevation provides an optimal PCAs, which potentially can be protected to withstand both nature conservation and timber production. The site selection for PCAs should consider both quality and quantity factors. Quantity refers to the amount of the availability of the area, while quality denotes the value of the area. In this study, site quality factors including forest ownership, accessible road, forest vegetation, and designated protected parks at the intermediate elevation gradient were further analysed.

There are three neighbouring villages as indicated in the study area section. Most of the high elevation area located at the Kunigami village. Therefore, Kunigami village would be the biggest contributor to the PCAs compared to the other villages. Table 1 showed the PCAs at intermediate elevation category (150 to 300 m a.s.l) with 50 m intervals. For example, at 200 m a.s.l Kunigami village contributed 31.3% of the village area for a conservation site while Higashi and Ogimi contributed 18.9% and 12.2%, respectively.

Table 1. The percentage of PCAs in each village at the intermediate elevation category

Village name	200 m	250 m	300 m
Kunigami	31.3	15.3	7.3
Higashi	18.9	6.7	3.4
Ogimi	12.2	6.2	2.5

Various landowners exist in this study area as illustrated in Figure 4. At the intermediate elevation level, the village or municipality forests hold about 13,639.6 ha, followed by the National, individuals, and prefectural forests, as presented in Table 2. Zoning deliberates an interest in each asset of the landowner to those who control the political power of the locality [7]. This factor is highlighted because if the zonation plan for conservation is to be formalised, support from the landowners is a crucial factor that greatly influences the smoothness of the zoning process especially participation from the forests owned by the village and individuals.

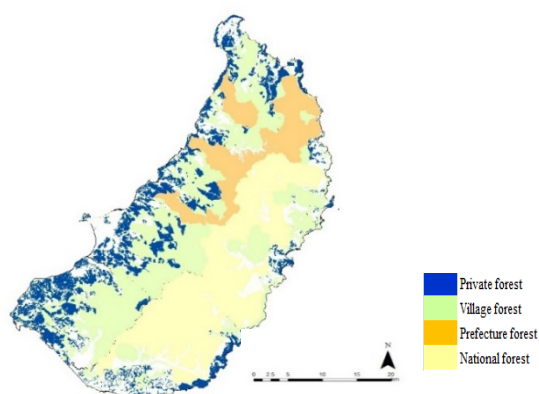


Figure 4. The forest ownership map of Okinawa forest area.

Table 2. Forest ownership in the Okinawa.

Forest owner	Total area (ha)
Village/municipal	13639.6
National	7553.4
Individual	4169.0
Prefecture	3386.6

Forest managers have their own management goals and barely focussed to the importance of conservation or protection areas, especially when timber production is the main management goal. The results from this study provide an indication to the authorities or specific agencies concerning the efforts that are required to inform the forest owner on the new forest landscape management by the zoning system. It is also to raise conservation awareness among the community. If ownership transformation is needed, a good negotiation is a prerequisite, and compensation payment should be

well-planned before transforming the area for conservation sites to avoid problems related to forest ownership in the future.

An increase in elevation changes the availability of wildlife habitat and vegetation structure. In this study, we overlaid the 946 ha of wildlife sanctuary areas and the 249 ha of protected prefectural parks with the PCAs at the intermediate elevation level. The analysis showed that 95% of these parks were intersected with our PCAs output. Non-flying mammals and birds had the highest number of species at mid-elevation [8]. For example, *D.noguchii*, the critically endangered (CR) flightless bird species of Okinawa, builds its nest in large *C.sieboldii* trees, which are usually found in the old-growth forest at the middle-peak of the Okinawa forest [9]. Therefore, it is important to conserve the middle peak region of the Okinawa forest from habitat fragmentation, particularly by anthropogenic disturbance, which is the main factor contributing to the extinction of wildlife species [10].

At 250 m of elevation, forest vegetation was calculated with average tree height was at 11.6 m, higher compared to 200 and 300m with 11.4 m and 10.6 m, respectively. The findings were supported by [11] where he pointed out that vegetation at the mid-elevation peak is characterised by most abundant with optimal tree height. The decreasing number of animals and plant species at the highest elevation was expected and has been verified by many studies [12,13,14]. Since no harvesting practice has been conducted in the National Forest area occupied for North military training sites, it was predicted that the area consists of large trees and high-quality timber [15].

The forest road network in Okinawa has been constructed across the forest area. There are two types of forest road, prefectural and village's road. The roads provide corridors for travel and access to recreational and forest educational areas. Forest road information can assist in estimating the number of forest visitors and it is important in measuring forest carrying capacity in terms of the ability of the forest area to support the number of visitors per time. The main forest road built across the PCAs at the middle elevation gradient was the Ookuni Forest Road, with a total length of 35,537.3 m. The total length of the forest network reduced significantly with elevation. Forest roads alter animal behaviour, change their home range [16] and limit habitat area and migration of the flightless bird of *G.okinawae* [17]. Under the Forestry Act, conservation forest is designed not only for public benefit but also to provide shelter for animals and plants [18]. Therefore, at a higher elevation with fewer accessible road networks animal mortality particularly associated with the roadkill cases could be reduced. The slope stability changes with forest road construction and it is related to the forest hydrological factor. Streams and watershed areas are decisive hydrological linkages that require the finest management strategy. In the study, the watershed area was found to cover 80% of the potential conservation area at the middle-peak altitude. Conserving the forest is a way to protect the watershed areas and natural resources. The watershed areas upsurge forest biodiversity by providing an abundant supply of water and nutrients to promote vegetation growth [19]. Therefore, it is a necessity to protect the areas to ensure ample clean water sources for public use. The implications concerning vegetation, accessible forest roads, and water resources in the PCAs are summarised in Table 3.

Table 3. Average tree height, accessible forest road and water resources at the selected PCAs in the Okinawa forest.

Elevation (m)	Average tree height (m)	Total road length (km)	Total stream length (km)	Watershed area (ha)
200	11.4	96.0	60.2	5956.1
250	11.6	65.5	13.8	3091.6
300	10.6	34.1	3.8	1512.1

Next, we compared our PCAs results with the forest management plan proposed by the DAFF of Okinawa Prefecture. Figure 5 illustrates the overlaid PCAs with Okinawa Prefecture's planning map and Table 4 summarised the percentage of the area attached to the selected elevation gradients for each zone.

The total protection areas (a combination of core, buffer, water, and soil conservation areas) increase with elevation. At 300 m, 55% of PCAs were spatially joined with the zoning plan by the Okinawa Forestry Department, while at 250 and 200 m, the percentage of associated areas was at 51% and 44%, respectively. Forest conservation recommends restricting commercial timber operations. This is parallel to the results produced by our study where the inclusion of production forest declined with elevation. In addition, the area occupied by the U.S. military was also displayed the same trend.

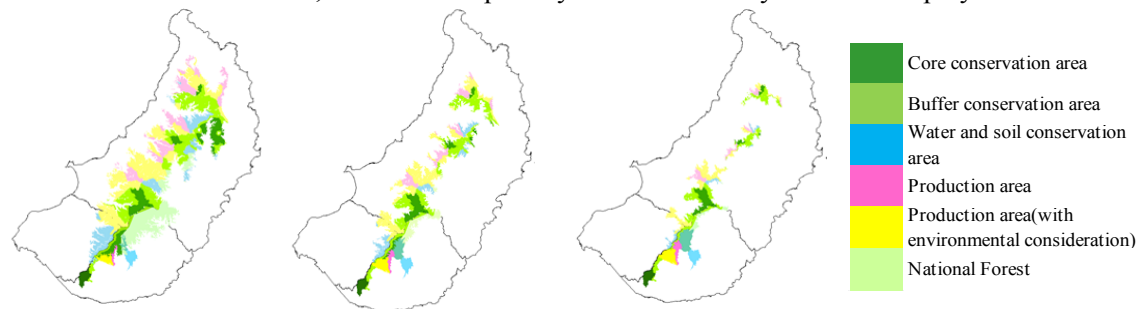


Figure 5. The overlaid map of a forest management plan based on forest functions by the DAFF of Okinawa Prefecture with the selected PCAs produced in this study. From the left: at elevations of 200 m, 250 m, and 300 m.

The comparison between the PCAs and the zoning plan of the Okinawa area was slightly different, particularly in respect of the allocation of conservation sites. More than 50 % of the conservation areas suggested in this study corresponded to the Okinawa Prefecture's zoning plan. Our study proposed to protect the middle elevation areas that consist of neither too small nor too large an area for protection. At this level, the PCAs were characterised by a continuous connection between forest patches not fragmented by forest functions. In consideration of UNESCO's proposal to realize the establishment of the National Park in Okinawa Forest, zoning by elevation showed this advantage. This shows that the elevation gradient is an applicable and practical parameter to describe the best site selection for conservation priority areas in the Okinawa forest.

Table 4. The percentage protection and production areas at different elevation levels.

Elevation level	Protection area (%)			Production area (%)		National Forest (%)	Unclassified area (%)	Total PCAs (ha)
	core	buffer	water and soil	with environmental considerations	without environmental consideration			
200 m	10.8	22.4	11.1	25.9	12.0	13.9	3.8	8043.8
250 m	11.0	30.1	9.5	29.9	10.3	7.2	1.9	3702.2
300 m	15.3	32.8	6.4	27.2	10.0	5.7	2.5	1774.6

Elevation gradients hold enormous potential to understand the factors underlying the global biodiversity [20] as different elevation gradients consist of different landscape and environmental characteristics. Among the pioneers who studied how the natural world changes with elevation are Wallace and von Humboldt [12]. Forest composition, functional processes, climate, and habitats were structurally changed along elevation gradients [21,22]. Precipitation and solar radiation increased, conversely air temperature and air pressure decreased with an increase in altitude. Generally, species richness peaks at mid-elevation depending on the species and sites, but it rarely increases with elevation [23].

4. Conclusion

The elevation gradient is a crucial parameter that corresponds to the UNESCO site selection, particularly in the decision-making process. The practicability of elevation integrated with accessibility, forest vegetation, and other data is hoped to provide a better understanding of site selection for conservation and to raise community awareness of the benefits of conserving the forest area. Among the many zonation scheme alternatives, this quantitative method can assist the zoning process with minimum cost, time, and effort. In allowing competing demands for development and other human activities, conservation sites require to be as small as possible with fewer patches and have connections between forest areas. Taking into account the influence of forest ownership, protected parks, watershed areas, vegetation, and forest accessibility, it was suggested that a conservation priority site for Okinawa forest located at the middle-peak elevation (150-300 m a.s.l.) exhibit the optimum conditions for conservation site. An increase in the elevation changed the habitat availability and vegetation structure. Hence, at this elevation level, fewer accessible roads were detected and major designated protected parks were also included. In the suggested PCAs, various stakeholders hold land areas with different management goals. Therefore, support from landowners is a crucial factor that greatly influences the smoothness of the zoning process. Half of the suggested PCAs were identical to the zoning plan by the Okinawa prefecture. This showed the significant use of elevation gradients to obtain the best site which should be selected for conservation purposes in the Okinawa forest.

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