Population density of snow leopards (Panthera uncia) in the Yage Valley Region of the Sanjiangyuan National Park: Conservation implications and future directions

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ABSTRACT

Population-based studies on snow leopard (Panthera uncia) are of theoretical and practical significance for the conservation of alpine ecosystems, though geographic remoteness and isolation hinder surveys in many promising regions. The Sanjiangyuan National Park on the Tibetan Plateau is acknowledged as a main snow leopard habitat, but most of the region remains unexplored and unknown. We adopted a combined approach of route survey and camera trapping survey to explore the population density of snow leopard in the Yage Valley region of the Sanjiangyuan National Park. Results indicated that (1) large populations of blue sheep contributed to the major food supply for snow leopards, along with diverse prey species as dietary supplementations, and (2) a population density of four to six snow leopards per 100 km\textsuperscript{2} on the north bank was estimated, and nine to fourteen individuals within the valley core areas were identified. We also argue that under the potential impacts of hydropower dams, this valley ecosystem should be symbolized as a conservation hotspot and therefore merits prioritized conservation. We recommend further surveys combined with novel methods/techniques and advocate a sustainable ecotourism model for the first V-shaped valley along the Yangtze mainstream.

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Introduction

The snow leopard (Panthera uncia) is well recognized as an indicator of ecological health in high altitude ecosystems, as well as a flagship species for promoting initiatives of alpine biodiversity conservation (Jackson and Hunter 1996). Threatened by poaching, retaliatory killing, prey base depletion, habitat degradation, and lack of conservation, snow leopards are emphasized as endangered animals that require urgent and consistent conservation efforts (International Union for Conservation of Nature 2014).

The current home range of snow leopards is restricted to high mountains across twelve Asian countries, and China is well known as the single most important country containing as much as 60 percent of all potential habitats (McCarthy and Chapron 2003). The Sanjiangyuan National Park (SNP; headwater regions of the Yangtze, Yellow, and Mekong Rivers) on the Tibetan Plateau has been identified as a hotspot area because of the discoveries of high population densities of snow leopards (Liao 1985; Schaller, Ren, and Qiu 1988). However, there is little or negligible baseline on the territories and demographic characteristics available in the published literature on this endangered top-order predator. Moreover, knowledge about the population density of snow leopards in the SNP remains sketchy given that large parts of potential habitat range have not been surveyed yet.

The Yage Valley of the SNP is in geographic proximity to an active area for the interaction between snow leopards and other carnivores (Li et al. 2013). This region is both topographically and geomorphologically promising as suitable habitats for snow leopards. However, scarce information leaves several important questions unaddressed: (1) What is the status of food supply for snow leopards in this valley? (2) How many snow leopard individuals inhabit this region? (3) What is the associated significance for China’s biodiversity conservation in alpine ecosystems? To answer these...
questions, we evaluate snow leopards’ available prey species, estimate the individual number and population density of snow leopard, and discuss the conservation implications and future directions regarding China’s alpine ecosystems. The findings of this research provide scientific evidence on the conservation of this elusive mammal in China, as well as scientific baselines for the conservation of alpine ecosystems in other regions.

Materials and methods

Study area

This study was concentrated in the Yage Valley region (34°20’ N, 93°50’ E; Figure 1) of the SNP on the eastern Tibetan Plateau, western China (Figure 1). The region consists of a narrow valley and adjacent rugged mountains with altitude ranging from 4,125 to 5,874 m. The Yangtze cuts through the landscape surfaces with a rushing current, forming the first V-shaped valley system (about 500–1,000 m deep and 10 km long) along the mainstream. The high and steep terrain, mainly formed from limestone, lava, and conglomerate, is strongly broken by cliffs, ridges, gullies, and rocky outliers. The climate is characterized as cold and humid with an average annual temperature of −2.0°C and average annual precipitation of 413.9 mm. Vegetation cover is classified as alpine grassland (primarily Stipa and Carex), alpine meadow (primarily Kobresia), and alpine desert (Tang et al. 2014). Large mammalian fauna mainly include blue sheep Pseudois nayaur, Tibetan brown bear Ursus arctos, Himalayan marmot Marmota himalayana, red fox Vulpes vulpes, Tibetan fox Vulpes ferrilata, and Pallas’s cat Otocolobus manul (Mallon and Bayar 2004). Pastoral areas are scattered in lower and flatter meadows, separating the rugged terrain from neighboring mountainous environments (Figure 1). Domestic livestock grazing rarely occurs in the core area of the Yage Valley.

Route survey

To estimate the population density of snow leopards, it is necessary to select an isolated habitat distinct from the surroundings for area calculation. Retaliatory killing has become a major threat to snow leopards’ survival (Bagchi and Mishra 2006), and intensified livestock grazing places increasing stress on snow leopard habitats (Forrest et al. 2012). We designed the survey route as a closed curve to encircle the rugged mountain terrain on the north bank of the Yage Valley, connecting scattered nomadic group camping sites and stream segments (Figure 1). We assumed that domestic livestock were normally guarded by herdsmen and dogs, and snow leopards were unlikely to swim in cold and fast-running rivers. Therefore, pastoral settlements and river barriers together restricted the movement range of snow leopard, making the population density estimable. Using ArcGIS 10.1 software (Esri Incorporated 2012), we roughly calculated an area of 225 km² for the enclosed home range of snow leopards on the north bank, of which at most two thirds (150 km²) was designated as suitable habitats after the exclusion of predominant pasture on the lower and less rugged land. The change in mountain ungulates abundance is crucial for the population status of snow leopard (Jackson et al. 2006). Therefore, the diversity and population size of ungulates act as indirect indicators of snow leopard population density. The route survey along the land track was conducted in January 2014. We visited nomadic group camping sites by driving to interview local herdsmen about ungulate species and their preferred places. We were informed that large groups of blue sheep frequently showed up on bank slopes in the core area of the Yage Valley. Therefore, we conducted a visual census of ungulates by drifting through the valley on rubber boats at speeds less than 5 km/h. The route survey along the water track was made once a month from May to October 2014. The detection probability of an ungulate is represented as a percentage.

Figure 1. The Yage Valley region in the Sanjiangyuan National Park on the Tibetan Plateau, western China, showing the rugged terrain on the north bank and the camera trap layout in the valley. Capital letters are references to camera trapping sites.
**Camera trapping survey**

Both track counts and camera trap rates have been widely utilized as indices of animal abundance and to predict population density (Rovero and Marshall 2009; Keeping and Pelletier 2014). We only focused on camera trap data and were unable to administer track count surveys due to logistic limitations. Camera trapping is a noninvasive, effective, accurate, and rapid tool for ecologists and conservationists. Its application in surveying and monitoring terrestrial mammals has gained increasing popularity in recent years (O’Connell, Nichols, and Karanth 2011; Burton et al. 2015). Snow leopards show a strong affinity for steep and rugged terrains and are rarely observed and followed in mountain environments. We used camera trapping to collect photographic evidence of snow leopards’ presence, to support the estimate of the individual numbers and population density. Firstly, we carefully selected several tributary valleys in the Yage Valley as potential trapping areas. Secondly, we organized detailed ground trace surveys in these areas in May and July 2014. Related findings and herders’ knowledge suggested that strategic positioning of camera traps along travel corridors and active scent rocks could greatly enhance capture rates. Therefore, with as little human interference as possible, thirty-eight infrared-triggered cameras (Ltl Acorn 6210MC; able to take both high-resolution photographs and videos at every trigger event) were planted in eleven sites near the Yangtze mainstream, including cliff and boulder bottoms, narrow belts between giant rocks, and ridgelines close to vertical cliffs (Figure 1). To cover the most sight angles possible, one trap site held two to six cameras according to specific topographical conditions. This method was also used to capture other animals and identify the potential prey species of snow leopards. Results are presented as successful captures at camera trapping sites. The monitoring program started in early May 2013, and we gathered evidence between 20 May and 31 October 2014 for follow-up individual identification.

**Individual identification**

We adapted capture–recapture techniques to identify snow leopard individuals based on their distinct pelage patterns, especially in size, shape, direction, and color of spots and rosette shapes (Jackson et al. 2006). Good quality photographs and video screenshots of the tail, frank, or limb of snow leopards were organized by trapping site, type, date, and time and used to form an image database. We carefully analyzed all images to locate distinct pelage patterns, which was useful for individual identification based on guidelines modified from Heilbrun et al. (2003) and Jackson et al. (2006):

1. We reviewed and categorized video sections and photos, recording the similar body parts of snow leopard individuals, and then comparatively analyzed the differences in their pelage patterns. Adobe Photoshop (Adobe Systems Incorporated 2010) was used for image processing and comparison.

2. Pelage patterns on snow leopards were better defined and easily recognizable because the fur is shorter and the patterns are less prone to distortion, especially concerning body movement and posture. Therefore, the dorsal surface of the tail was prioritized as the primary feature, and other body parts such as the flank and limb were referred to as secondary features.

3. Varying body orientations and changes in light can lead to judgment errors. To enhance the correctness of identification, we set up a primary and secondary features protocol and used more than one body part for comparison. An estimate of one distinct individual was made by comparing the primary feature. If only side-profile photographs of snow leopards were available, an estimate of one indeterminate individual was made by comparing the secondary feature.

4. Comparing the pelage patterns on different body parts do not lead to valid identification. In this case, the trapping site, date, and time of capture were taken as supplementary references to determine whether targets were exclusive. Additionally, the trapping site, date, and time, combined with the comparison of body features, were used to determine whether the animal was an initial capture or recapture.

All three authors acted as observers and each manually and independently compared the results of capture–recapture estimates. We attempted to further limit observer bias and misidentification by confirming distinct individuals with consensus agreement by all observers (Clare, Anderson, and MacFarland 2015; Jacques et al. 2019).

**Results**

**Available prey species of snow leopard**

Carnivore species like snow leopards depend largely on mountain ungulates for prey. Our surveys revealed that there were at least five ungulate species in the core area of the Yage Valley, including blue sheep, white-lipped...
deer *Cervus albirostris*, Tibetan gazelle *Procapra picticaudata*, alpine musk deer *Moschus chrysogaster*, and kiang *Equus kiang*: blue sheep was the most abundant ungulate and about 300 individuals in two groups foraging on open bank slopes were visually counted; two groups of white-lipped deer consisting of 36 individuals were witnessed pacing on valley slopes; 28 individuals of Tibetan gazelle were directly sighted in small groups; and 3 and 1 individual kiang and alpine musk deer were observed, respectively (Figure 2). A total of six route surveys along the water track were administered, and the detection probability varied among species from 17 percent (Tibetan gazelle, alpine musk deer, and kiang) to 33 percent (blue sheep and white-lipped deer).

Camera traps successfully captured eight potential prey species of snow leopards at eleven trapping sites in the core area of the Yage Valley (Table 1). Blue sheep had the highest rate of successful capture at ten out of eleven trapping sites, followed by white-lipped deer and pika *Ochotona curzoniae*, which both were captured at five trapping sites. The successful captures of domesticated yak and Himalayan marmot were reported at four and three trapping sites, respectively. Alpine musk deer, woolly hare *Lepus oiiostolus*, and domesticated horse were successfully captured at only one trapping site.

There were about twenty-nine grazing sites on the surrounding mountainous rangelands (Figure 1). The livestock assemblage mainly included sheep and yak. One herding family possessed around 2,000 sheep and 300 cattle. Livestock depredation incidents were reported from time to time due to snow leopards’ predatory behaviors.

### Snow leopard population density

The Yangtze mainstream and its tributary, as natural separations, cut off the population exchange of snow leopards between both banks and favor the assessment on population density. There is a slight possibility that snow leopards could swim across rapid flows for both intra- and interspecies communications. Therefore, we estimated the sample population at six to nine individuals in the rugged mountain terrain on the north bank, with six distinct (Table 2; Figure 3) and three indeterminate (Table 2; Figure 4), and three to five individuals on the south bank area, with three distinct (Table 2; Figure 5) and two indeterminate (Table 2; Figure 6). A total of nine to fourteen individuals were captured in the core area of the Yage Valley. Additionally, no female snow leopards with cubs were detected during the research period.

Thus, we conservatively concluded a population density of four to six cats per 100 km² within the range on the north bank of the Yage Valley. We could not make credible surveys on ground investigations and camera traps for the range on the south bank due to logistic limitations.

### Discussion

#### Prey diversity and abundance

Snow leopards have strong dietary requirements for mountain ungulate preys throughout their home ranges, such as Siberian ibex *Capra sibirica*, blue sheep, Himalayan tahr *Hemitragus jemlahicus*, and argali *Ovis ammon* (McCarthy and Chapron 2003). The blue sheep in large-sized packs found in the Yage Valley emphasizes the important role of this ungulate in maintaining the population stability of snow leopard (Schaller 1998). Other medium-sized herbivores like white-lipped deer and alpine musk deer constitute suboptimal but

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**Table 1. Potential snow leopard prey species captured by camera traps in the core area of the Yage Valley.**

| Common name          | A | B | C | D | E | F | G | H | I | J | K |
|----------------------|---|---|---|---|---|---|---|---|---|---|---|
| Blue sheep           | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ |   |
| White-lipped deer    |   |   |   |   |   |   |   |   |   |   |   |
| Alpine musk deer     |   |   |   |   |   |   |   |   |   |   | √ |
| Himalayan marmot     | √ | √ | √ | √ |   |   |   |   |   |   |   |
| Pika                 |   |   |   |   |   |   |   |   |   |   |   |
| Woolly hare          | √ | √ | √ | √ |   |   |   |   |   |   |   |
| Domesticated yak     |   |   |   |   |   |   |   |   |   |   |   |
| Domesticated horse   |   |   |   |   |   |   |   |   |   |   |   |

Notes. Capital letters are references to camera trapping sites. The symbol √ indicates successful captures.
Table 2. Capture details of snow leopard individuals in the core area of the Yage Valley.

| Bank | No.* | Image type | Day or Night | Body part          | Date   | Time   | Exclusive |
|------|------|------------|--------------|--------------------|--------|--------|-----------|
| North | 1B   | Photo      | Day          | Tail               | 19 Oct | 13:42 | Yes       |
|      | 1F   | Photo      | Day          | Tail               | 12 Sep | 21:52 | Yes       |
|      | 2J   | Photo      | Night        | Tail               | 2 Jun  | 10:51 | Yes       |
|      | 3B   | Photo      | Day          | Tail               | 2 Jun  | 10:51 | Yes       |
|      | 4J   | Photo      | Day          | Tail               | 9 Oct  | 18:56 | Yes       |
|      | 4F   | Screenshot | Night        | Tail               | 25 Jun | 23:07 | Yes       |
|      | 5B   | Screenshot | Night        | Tail               | 23 Oct | 2:21 | Yes |
|      | 5I   | Screenshot | Night        | Tail               | 9 Oct  | 22:09 | Yes |
|      | 6F   | Screenshot | Day          | Tail               | 2 Jul  | 19:11 | Yes |
|      | 7A   | Photo      | Day          | Left flank and hindlimb | 28 Aug | 19:13 | No |
|      | 8F   | Screenshot | Night        | Left flank and hindlimb | 14 Oct | 7:33 | No |
|      | 8F   | Photo      | Day          | Left flank and hindlimb | 14 Oct | 18:38 | No |
|      | 9F   | Photo      | Day          | Left flank and hindlimb | 25 Jul | 20:47 | No |
|      | 9F   | Photo      | Night        | Left flank and hindlimb | 4 Jul  | 21:04 | No |
| South | 1H   | Photo      | Day          | Tail               | 31 Aug | 18:55 | Yes |
|      | 1G   | Screenshot | Day          | Tail               | 16 Sep | 10:07 | Yes |
|      | 2H   | Photo      | Day          | Tail               | 7 Sep  | 18:20 | Yes |
|      | 3G   | Photo      | Day          | Tail               | 2 Sep  | 8:31 | Yes |
|      | 3E   | Screenshot | Day          | Tail               | 15 Sep | 17:26 | Yes |
|      | 4G   | Photo      | Day          | Right hindlimb     | 1 Oct  | 12:10 | No |
|      | 4C   | Photo      | Day          | Right hindlimb     | 1 Oct  | 10:51 | No |
|      | 5H   | Photo      | Day          | Right flank and hindlimb | 7 Sep  | 10:14 | No |
|      | 5K   | Photo      | Day          | Right flank and hindlimb | 11 Oct | 16:21 | No |

Note. *Arabic numbers in the No. column are references to possible individual snow leopards. Capital letters in the No. column are references to camera trapping sites.

Figure 3. Pelage pattern variations on the dorsal surface of the tail of snow leopards on the north bank of the Yage Valley. The six distinct individuals are numbered following capture details in Table 2. The Arabic numbers are references to possible individual snow leopards, and the capital letters are references to camera trapping sites (see Figure 1).
necessary prey for snow leopards (Lyngdoh et al. 2014). Their appearance in small amounts signifies alternative hunting targets if the preferred prey species of snow leopard becomes scarce in harsh seasons and environments. Tibetan gazelle and kiang are actively avoided by snow leopards, partially because they favor open alpine meadow and alpine steppe rather than rugged mountain terrain (St-Louis and Côté 2009; Leslie 2010). Information on the mutual responses between snow leopards and prey species is still lacking in the published literature, and more in-depth research is suggested to provide further clarifications.

Except for snow leopards’ preference for ungulates, we had no detailed data on their full dietary niche breadth.

Figure 4. Pelage pattern variations on the dorsal surface of the left flank and hindlimb of snow leopards on the north bank of the Yage Valley. The three indeterminate individuals are numbered following capture details in Table 2. The Arabic numbers are references to possible individual snow leopards, and the capital letters are references to camera trapping sites (see Figure 1).

Figure 5. Pelage pattern variations on the dorsal surface of the tail of snow leopards on the south bank of the Yage Valley. The three distinct individuals are numbered following capture details in Table 2. The Arabic numbers are references to possible individual snow leopards, and the capital letters are references to camera trapping sites (see Figure 1).
Pika and Himalayan marmot were locally discerned in high frequencies, but no accurate statistical results were obtained in this research. The possibility of biomass support by small-sized rodents should not be excluded, considering that they contribute a considerable portion of snow leopards’ ordinary diet (Schaller 1998).

Domestic livestock comprises a certain proportion of the diet of snow leopards (Bagchi and Mishra 2006; Anwar et al. 2011). Snow leopards’ predation on livestock can be significant in their home range (Jackson and Fox 1997) if fewer natural prey are available in difficult circumstances. In addition, snow leopard predation on domestic livestock often takes place in more rugged habitats outside of herders’ view (Johansson et al. 2015). Hence, domesticated yak, sheep, and horse grazing around the rugged mountain terrain on the north bank of the Yage Valley are alternative prey resources for snow leopards.

**High population density**

Snow leopards have a vast geographic range but sparse distribution at low density. An area of five to ten individuals per 100 km² based on available habitat could be distinguished as a hotspot (McCarthy and Chapron 2003). This criteria likely vary in different regions. For instance, a density of one cat per 25–35 km² was determined in the Yangtze source in Qinghai Province (Schaller, Ren, and Qiu 1988), where the available habitat is severely scattered and fragmented. Our research estimates a population density of four to six animals per 100 km², which is consistent with the above and expands the hotspot range to the SNP on the Tibetan Plateau. It must be noted that north bank individuals were not captured on the south bank and vice versa, suggesting that the river serves as a barrier for the exchange of snow leopards.

In comparison with our results, previous research reported high densities, such as 5.8–8.3 cats per 100 km² in the Ladakh Valleys of India (Green 1982), 5–10 cats per 100 km² in the Langu Valley of Nepal (Jackson and Ahlborn 1989), and 5 cats per 100 km² in the Altay of Mongolia (Schaller, Tserendeleg, and Amarsanaa 1994). However, these estimates were made over two decades ago when protected areas functioned better than they do at present (McCarthy and Chapron 2003). In addition, medium population densities were reported in other regions, such as the Tunkinskiy Range of Russia (1.5 cats per 100 km²; Koshkarev 1989), northeastern Bhutan (1–2 cats per 100 km²; Fox and Jackson 2002), and Xinjiang of China (0.44 cats per 100 km²; Schaller, Hong et al. 1988). Similarly, though, these results are out of date. Our findings suggest that the Yage Valley could be identified as a snow leopard hotspot. We recommend robust survey and monitoring designs in the Yage Valley region with particular concentration on the area north and west of our trapping sites. This survey, in its initial stage, faced inherent challenges and did not capture female snow leopards with cubs, which is important to assess population dynamics and viability. Follow-up studies should focus on filling this gap by studying larger areas and longer periods.

The density of snow leopard varies with region and regimes of disturbance, indicating that the estimate is context specific and scenario based. The remote and rugged mountain habitat of the species has rendered population surveys challenging. It is impossible to compute the population density of snow leopard in areas without boundaries. Our estimate, in a conservative manner, reflects the population density in the rugged mountain terrain on the north bank, where ranch lands and rushing rivers are temporary barriers. Additionally, seasonal factors bring about uncertainties because ranch
lands locations change or river surfaces are frozen in wintertime. In those cases, snow leopards might patrol in larger ranges due to easier accesses. The hotspot we suggested could be explained as the region with active interaction between snow leopards and sympatric species (Li et al. 2013) and emphasizes the conservation implications of China’s alpine ecosystem.

Conservation implications

Given its geographic remoteness and isolation, the Yage Valley is rarely disturbed by anthropogenic activities and hence forms a reliable refuge for rich wildlife. Our findings emphasize that diverse rare and endangered animals under nation-level protection are harbored in this region, such as snow leopards, white-lipped deer, and alpine musk deer. In addition, a well-maintained alpine meadow ecosystem supports the mammal fauna prosperity within the valley (Tang et al. 2014), explaining the positive role of the productive herbaceous biome on the high density of blue sheep (Aryal, Brunton, Ji, and Raubenheimer 2014). This is relatively uncommon on the Tibetan Plateau, where overgrazing has led to widespread degradation of meadow communities. Therefore, it is indicated that valley systems in the SNP act as intact eco-regions with the presence and survival of top-order predators (Li et al. 2013). This is in concordance with our expectation that the Yage Valley could be symbolized as a conservation hotspot and merits prioritized and comprehensive conservation efforts.

Human–carnivore conflicts raise urgent challenges in the conservation of snow leopards as expanding grazing pressure compels wildlife into habitat fragments. The distribution of ranch lands in the study area also assumes that livestock grazing activities and the habitat use of snow leopard are conditionally compatible (Sharma, Bhatnagar, and Mishra 2015). Such a relation underlines the ethical importance of the connection between legal and animal geography and the conservation implication of making legal carnivore territory (Ojalammi and Blomley 2015). Our initial analysis could help local and conservationist authorities harmonize conservation programs on both wild prey abundance and livestock-grazed landscapes (Suryawanshi et al. 2013) and add referential insights into the future of human–carnivore coexistence.

Future directions

The use of camera trapping and related matters is laborious and time consuming (Jackson et al. 2006). Due to the limited camera trapping coverage, the evaluation of snow leopard population abundance and density is conservative. We encourage subsequent studies to integrate novel methods and techniques to provide more accurate and thorough representations. For instance, it is informative to characterize and monitor snow leopard habitats using remote sensing data sets (Gupta et al. 2004) and to predict negative impacts in combination with climate change models (Convery et al. 2015); the analysis of fecal samples can improve the census of snow leopard individuals based on DNA microsatellite makers and reveal their diet preferences according to hair from prey species (Aryal, Brunton, Ji, Karmacharya et al. 2014). The use of a pattern recognition algorithm would increase the accuracy and efficiency of morphological identification (Oksana 2010).

China’s hydropower ambitions have stretched from middle and downstream areas to the source regions of big rivers. Heavy hydroelectric development for as a cascade of hydropower stations has been planned in the Yangtze mainstream. One dam with a height of 44 m, normal water level of 4,410 m, installed capacity of 63.6 MW, and catchment area of 63,047 km² was planned at the mouth of the Yage Valley (Yi et al. 2007). This project would produce immediate effects on the ecosystem, making the area less suitable for native inhabitants. As a result, some of our trapping sites would be submerged by impoundment of the reservoir. Furthermore, the existing biological communities could be at risk due to irreversible degradation of landscape integrity. Therefore, how to balance economic development and ecological conservation has far-reaching influences on regional sustainable development in the future. From another perspective, the attraction of the first valley system along the Yangtze mainstream is because the landscape is free from anthropogenic activities. Rather than permanent landscape damage triggered by hydropower dams, we advocate a future direction for the Yage Valley as a pilot site for controlled ecotourism in China, following a low-volume and high-yield sustainable model in Bhutan (Nyaupane and Timothy 2010).

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