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A GIS Approach to Estimating Tourists' Off-road Use in a Mountainous Protected Area of Northwest Yunnan, China

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To address the environmental impacts of tourism in protected areas, park managers need to understand the spatial distribution of tourist use. Standard monitoring measures (tourist surveys and counting and tracking

techniques) are not sufficient to accomplish this task, in particular for off-road travel. This article predicts tourists' spatial use patterns through an alternative approach: park accessibility measurement. Naismith's rule and geographical information system's anisotropic cost analysis are integrated into the modeling process, which results in a more realistic measure of

off-road accessibility than that provided by other measures. The method is applied to a mountainous United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage Site in northwest Yunnan Province, China, where there is increasing concern about potential impacts of unregulated tourist use. Based on the assumption that accessibility tends to attract more tourists, a spatial pattern of predicted off-road use by tourists is derived. This pattern provides information that can help park managers develop strategies that are effective for both tourism management and species conservation.

Keywords: Protected area; tourism; spatial distribution; time-based accessibility; Naismith's rule, northwest Yunnan.

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Introduction

National parks, heritage sites, and other protected areas (all called parks hereafter) are increasingly important for nature-based tourism. They are the primary places chosen by most people who want to enjoy nature (Eagles and Cool 2002). Demand for park tourism has been increasing around the world (Balmford et al 2009). Emerging economies (eg China and India), in particular, have reported rapid growth of park tourism in the last decade (Li et al 2008; Karanth and DeFries 2011).

Park tourism can generate significant revenues that can help fund conservation and community development efforts (Rai and Sundriyal 1997; Kruger 2005; Saayman and Saayman 2006; Mayer et al 2010; Nyaupane and Poudel 2011). However, public access is not always compatible with the conservation objectives of parks (eg conservation of biodiversity or provision of ecosystem services). There is growing evidence that tourism activities have negative impacts on biological resources (as a result of resource extraction, wildlife disturbance, and habitat degradation) and physical environments (as a result of increased soil compaction, water pollution, and fire frequency) (Hammitt and Cole 1998; Sun and Walsh 1998; Newsome et al 2002; Pickering and Hill 2007; Pickering

and Mount 2010; Tomczyk 2011; Zhong et al 2011). It is important to understand these tourism-related impacts to formulate sustainable park conservation objectives.

Sound knowledge of tourist use will improve the ability to understand the impacts of tourism. However, data on tourist use in most parks, in particular on spatial distribution, are sparse (Hornback and Eagles 1999; English et al 2004). Limited resources (financial or personnel), multiple access points, and logistic difficulties (eg large size) have been identified as some of the reasons for this. Another problem is the lack of efficient methods to estimate tourist use (Hornback and Eagles 1999; Skov-Petersen and Gimblett 2008). Tourist surveys (eg questionnaires or interviews), which are commonly used by park managers in tourist monitoring programs, are resource intensive and usually inaccurate. For instance, they fail to capture dispersed activities such as off-road travel, because people are reluctant to report their access to restricted areas (Cope et al 2000; Cessford and Muhar 2003).

Modern counting equipment, including cameras, infrared sensors, and pressure pads, can collect tourist distribution information accurately and efficiently. However, they are expensive, and their use is usually limited to the main entrances and road and track heads

(Xia and Arrowsmith 2008; Pettebone 2009). Newly developed tracking techniques, such as cellular phone triangulation and global positioning systems (GPSs), have become attractive options for tourist studies (D'Antonio et al 2010). However, cell phone coverage in most parks is sparse (compared with urban areas), and dense tree cover and rugged terrain can substantially affect reception of signals from land-based stations and satellites. This drawback makes these techniques less feasible for collecting information about park tourists in mountain areas (Shoval and Isaacson 2010).

This article proposes an alternative method of estimating spatial patterns in tourist use: park accessibility measurement with a geographical information system (GIS). It focuses on off-road use, which is the most difficult to estimate and most likely to have detrimental biophysical effects on natural resources (Marion and Leung 2004; Dumont et al 2005; Leung et al 2011; Wimpey and Marion 2011).

The method combines Naismith's rule for estimating walking time with GIS anisotropic cost analysis to map off-road accessibility. Accessibility is defined as the one-way travel time to any roadless location within a park from the nearest point of mechanized road or track access. Naismith's rule is used to calculate the time it takes to walk over rough and uneven terrain. It allows a more realistic estimate of the accessibility of rugged terrain than that provided by distance alone (Carver and Wrightham 2007; Carver et al 2012).

The objectives of this study were to (1) present a GIS method for predicting the spatial distribution of tourist off-road use of mountainous parks through time-based accessibility measurement, taking into account linear distance, relative slope, and ground cover; (2) examine how park accessibility is likely to change with different management options, as represented by 2 access scenarios; and (3) demonstrate how the resulting accessibility map can be used to support park conservation practices, such as setting conservation priorities for rare or endangered species. The study area is located in a United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage Site in the mountainous part of northwest Yunnan Province, China, where conservation efforts are increasingly challenged by tourism development.

Theoretical background

Naismith's rule

Naismith's rule is used to estimate walking time over rough terrain. Devised by Scottish mountaineer William Naismith in 1892, it estimates a walking speed of 5 km/h on level ground with an additional 0.5 hour for every 300 m of ascent (Aitken 1977; Carver and Fritz 1999). The rule has been refined based on other empirical tests (Carver and Wrightham 2007; Scarf 2007). Langmuir

(1984) subtracted 10 minutes per 300-m descent for slopes between 5 and 12° and added 10 minutes per 300-m descent for slopes greater than 12°. This correction makes the rule applicable to both uphill and downhill walking.

Some researchers argue that the rule and its refinements are limited to reasonably fit hill walkers negotiating typical terrain under typical weather conditions and do not account for variations in conditions underfoot, fitness, and load carried (Aitken 1977; Fritz and Carver 2000; Scarf 2007).

GIS anisotropic cost analysis

Cost analysis is now a standard function of most raster GIS. It results in a friction surface that indicates the relative difficulty of moving through each cell or pixel. This function is increasingly being used for tasks such as land suitability evaluation for site selection (Eastman et al 1995; Nikolakaki 2004) and route and corridor planning (eg in the case of animal migration and dispersal routes) (Adriaensen et al 2003; Li et al 2010).

The philosophy and methodology of cost assignment are well documented in geospatial analysis packages (eg Idrisi GIS and ArcGIS). In short, the cost of a cell in terms of money, time, or energy is compared to a base cost. In most cases, cost or "friction" is identical regardless of the direction in which one moves through a cell, but some costs, called anisotropic (Collischonn and Pilar 2000; Ganskopp 2000; Ray and Ebener 2008), are different in different directions. For example, in the case of slope, walking uphill requires more effort and time than walking downhill at the same speed.

GRASS software and the *r.walk* module

Few GIS packages supply adequate algorithms to address the anisotropic cost of slope when measuring walking time. A notable exception is the *r.walk* module in the Geographic Resources Analysis Support System (GRASS, <http://grass.osgeo.org>). GRASS is a free, open-source GIS package. More than 400 modules have been developed that cover a range of applications from traditional GIS functions in land management and environmental modeling to new areas in response to developments in 3-dimensional mapping and geospatial technology (Mitasova and Neteler 2004; Neteler et al 2012).

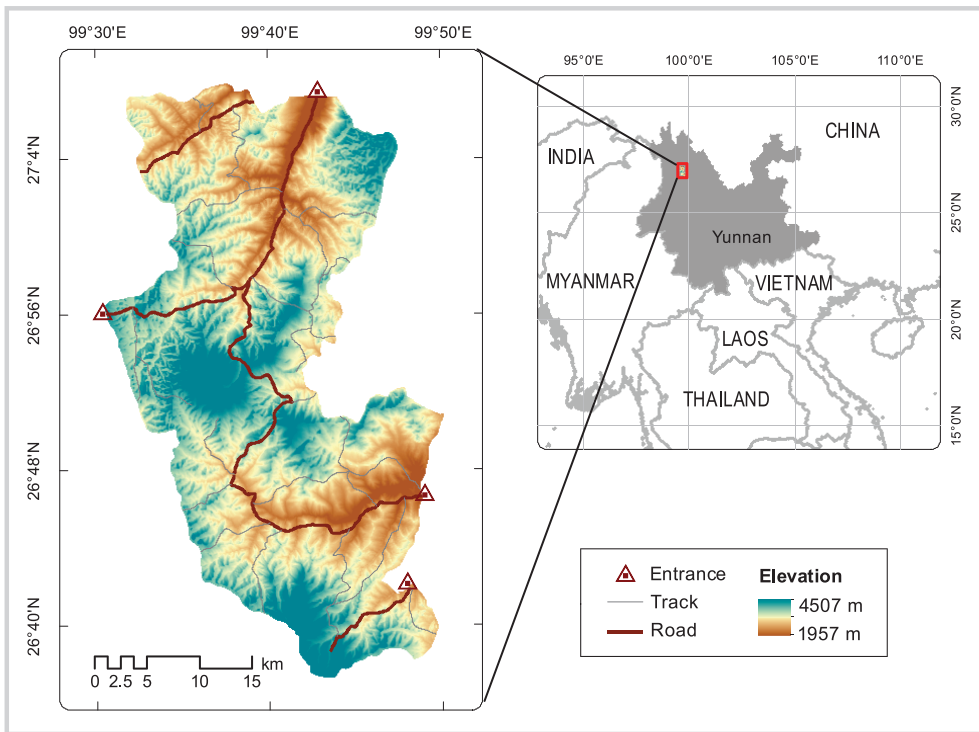
Naismith's rule, as refined by Langmuir, is implemented in GRASS as a module (*r.walk*) addressing the effects of slope on the time required to walk over rough terrain (Neteler and Mitasova 2008). The module calculates different walking times for uphill and downhill movement based on the following algorithm:

$$T = a \times \Delta S + b \times \Delta H_u + c \times \Delta H_d + d \times \Delta H_s \quad (1)$$

where

- a is the time it takes in seconds to walk for 1 m on a flat surface (slope $\leq 5^\circ$);

FIGURE 1 Laojun Mountain World Heritage Site: location, elevation, roads, and tracks. (Map by Mingyu Yang)



- ΔS is the horizontal distance in meters;
- b is the time penalty, in seconds of additional walking time, per meter of elevation gain on uphill slopes ($>5^\circ$);
- ΔH_u is the amount of elevation gain across ΔS on uphill slopes ($>5^\circ$);
- c is the time gain, in seconds of additional walking time, per meter of elevation loss on moderate downhill slopes ($5\text{--}12^\circ$);
- ΔH_d is the amount of elevation loss across ΔS on moderate downhill slopes ($5\text{--}12^\circ$);
- d is the time penalty, in seconds of additional walking time, per meter of elevation loss on steep downhill slopes ($\geq 12^\circ$); and
- ΔH_s is the amount of elevation loss across ΔS on steep downhill slopes ($\geq 12^\circ$).

Using this algorithm, time estimates produced by the Naismith–Langmuir rule are tied to terrain variables (horizontal distance, elevation gain or loss, and slope), resulting in an anisotropic cost surface that shows the time needed to move among locations (Neteler and Mitasova 2008; Ullah 2011).

Material and methods

Study area

The Laojun Mountain Area ($26^\circ 37'\text{--}27^\circ 09'\text{N}$, $99^\circ 30'\text{--}99^\circ 50'\text{E}$) is 1 of 8 geographical clusters in the Three Parallel Rivers of Yunnan Protected Areas UNESCO

World Heritage Site. It is located in the mountainous part of northwest Yunnan Province, China (Figure 1). The area extends more than 1084 km^2 and ranges from 1957 to 4507 m in elevation. Most of the terrain is rugged; slopes vary between 0 and 79° .

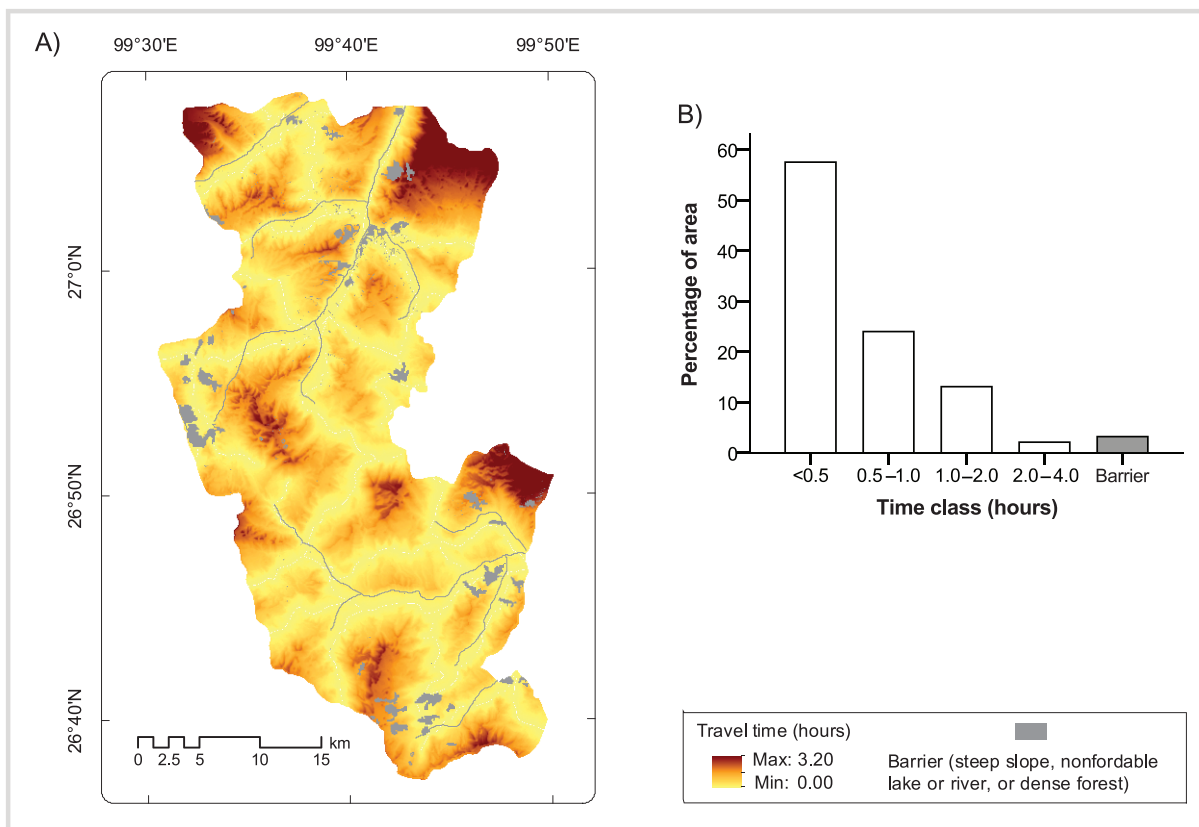
Montane, alpine, and subalpine ecosystems dominate the area. Temperate coniferous forests (pine, spruce, and fir) and a mosaic of alpine and subalpine landscapes (scree, meadow, and shrubland) constitute its natural appearance, with some features resulting from century-old use (farming, herding, and logging) by small local ethnic groups (Buntaine et al 2007).

Since the late 1990s, tourism has emerged as an alternative development trajectory offering a way to support nature conservation and alleviate poverty (Zhou and Grumbine 2011; Zinda 2012). The Laojun Mountain Area has become an important site for outdoor recreation (especially for hiking and wildlife viewing). In 2009 (most recent data collection available), more than 80,000 tourists visited the area. Tourist access is not restricted, and tourists travel on existing roads and tracks that are primarily used for farming or herding (Figure 1).

Estimating walking time

To support computation using GRASS's *r.walk* module (release 6.4.1), a digital elevation model (DEM) of the study area with 25-m resolution was acquired from China's National Administration of Surveying, Mapping, and Geoinformation (NASMG), constructed in 2002 based

FIGURE 2 Study area under scenario A. (A) Estimated walking time from nearest road or track; (B) percentage of area within each time class.



on topographic maps and airborne photogrammetric imagery. Slope and other topographic attributes used in Equation 1 were derived from this DEM.

We assumed that tourists could stop at any point along existing roads or tracks and walk through a roadless area to the park boundary. The road and track dataset was derived from topographic maps (produced by NASMG in 1970) and upgraded using GPS in 2006–2007.

The proposed values of a , b , c , and d in Equation 1 correspond to walking speeds under different slope conditions, where a is approximately 0.72 s/m, b is approximately 6.0 s/m, c is approximately 1.9998 s/m, and d is approximately -1.9998 s/m (Neteler and Mitasova 2008; Ullah 2011).

To render the model more realistically, natural barriers were considered when computing walking time. Very steep slopes ($\geq 60^\circ$), nonfordable lakes and rivers (≥ 5 m wide), and dense vegetation ($\geq 85\%$ understory cover) were represented by cells with a null value and excluded from computation. Slope data were derived from the DEM (through the *r.slope.aspect* module in GRASS). Large rivers and lakes were digitized from topographic maps. Dense vegetation was identified by combining a recent vegetation map derived from 2004 Land Satellite Thematic Mapper imagery by the Nature Conservancy Chinese program team and field experiences

of typical structure and floristic composition for each vegetative formation.

Comparing access scenarios

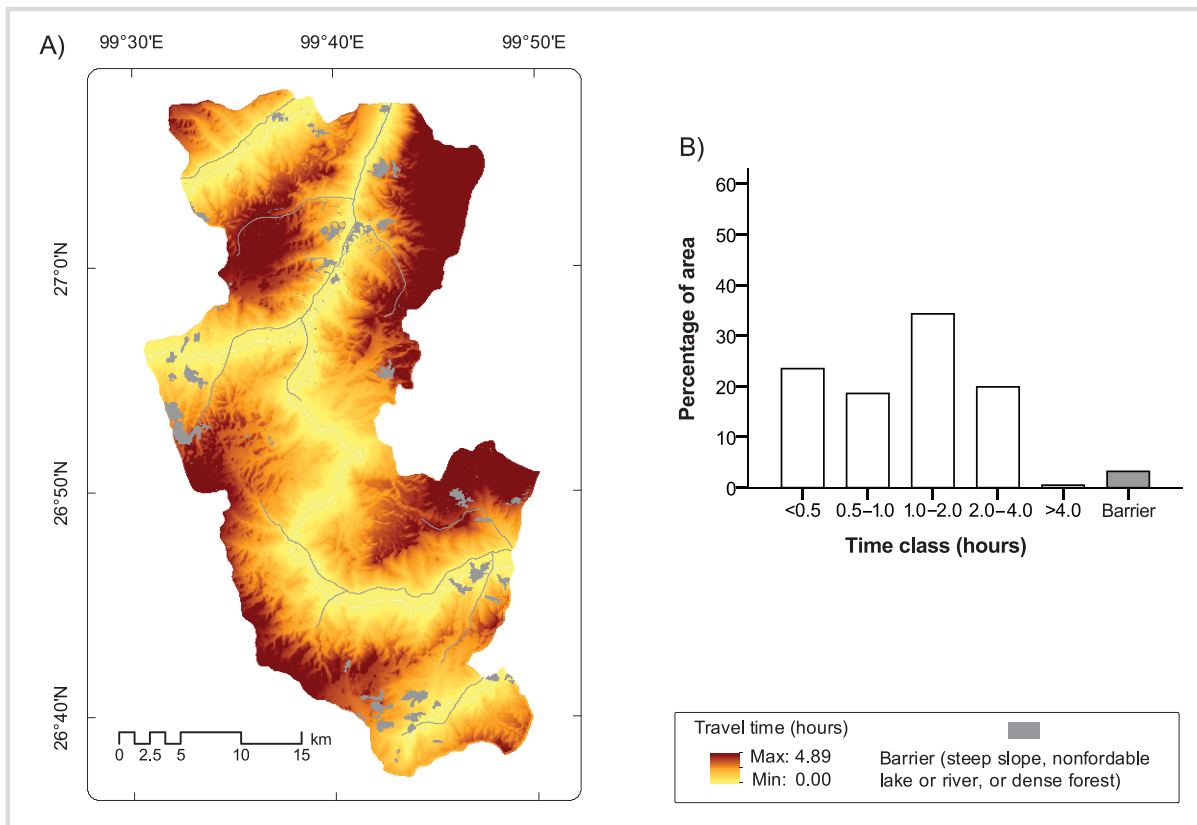
To examine how management options affect accessibility, we applied the time cost calculation to 2 tourist access and use scenarios: scenario A, based on the current unrestricted access to roads and tracks, and scenario B, based on restrictions on use of tracks.

Prioritizing rare or endangered species

The third objective of this study was to explore how the accessibility estimated earlier can inform park conservation policy in the context of tourism use. We took the case of rare or endangered plants as an example. A total of 30 rare or endangered plant species were identified in the study area during surveys conducted from 2001 to 2007 by local conservation biologists, park managers, and the authors.

Based on the assumption that the less time taken by tourists to reach a rare or endangered species, the greater the risk that this species will be disturbed or damaged by tourist activities, we used accessibility data as a proxy for measuring tourism's potential threat to rare or endangered plants. Such information may help park managers to make more informed decisions for allocating

FIGURE 3 Study area under scenario B. (A) Estimated walking time from nearest road; (B) percentage of area within each time class.



resources to monitoring and protection of species that are the most vulnerable.

Results

There are 58.6 km of roads and 91.3 km of tracks in the study area. Roads are open to vehicles, foot passengers, and livestock, while tracks are limited to foot passengers and livestock. Barriers to walking exist on 35.5 km² (3.3% of the study area). They consist of steep slopes (2.4 km²), nonfordable lakes and rivers (3.2 km²), and dense vegetation (29.9 km²), mainly shrubs dominated by *Rhododendron* and *Quercus* spp.

Figure 2 shows time-based accessibility in the study area under scenario A, in which tourist access is unrestricted. The average off-road access time—walking time from a road or track to a roadless location in the park—was 0.51 hour (with a standard deviation, or SD, of 0.50 hour). About 57% of the park can be reached within 0.5 hour, 82% can be reached within 1 hour, and 95% can be reached within 2 hours.

Figure 3 shows accessibility under scenario B, in which tourists are restricted to access and use tracks. This restriction is likely to significantly affect off-road accessibility. Maximum access time increases from 3.20 to

4.89 hours, while average access time rises from 0.51 to 1.27 hours (SD = 1.18 hours).

In area terms, large proportions of the area shift from the initial class with a short walking time (<0.5 hour) to the classes with long walking times (1–2 and 2–4 hours). A comparison of 2 scenarios using the kappa statistic (Pontius 2000; van Vliet et al 2011) indicates a low agreement level (kappa = 0.3159). The changes between the 2 scenarios are illustrated in an area transition matrix in Table 1.

Rare or endangered plants were found at 106 sites in the study area (Figure 4). These plants are targets of conservation management; all of them are on the national or provincial protection list, and some are on the International Union for Conservation of Nature (IUCN) Red List. Species are not evenly spread across the study area but cluster in its western and southern parts.

Figure 5 indicates the access time of each of the sites under the current management regime (scenario A). Scenario B was not considered in this study; however, it can follow the same method as scenario A to prioritize the species after access restrictions are implemented in the study area. The time to reach these sites under scenario A ranges from 0.04 to 2.25 hours, with an average time of 0.59 hour (SD = 0.48 hour). In total, 54 sites (50.9%) can

TABLE 1 Area transition matrix (based on the proportion of pixels) from scenario A (rows) to scenario B (columns) for each time class.^{a)}

Scenario A	Scenario B						Total
	<0.5 h	0.5–1.0 h	1.0–2.0 h	2.0–4.0 h	>4.0 h	Barrier	
<0.5 h	0.2352	0.0778	0.1781	0.0840	0.0000	0.0000	0.5751
0.5–1.0 h		0.1079	0.0851	0.0472	0.0000	0.0000	0.2402
1.0–2.0 h			0.0796	0.0500	0.0014	0.0000	0.1310
2.0–4.0 h				0.0181	0.0031	0.0000	0.0212
Barrier						0.0325	0.0325
Total	0.2352	0.1857	0.3428	0.1993	0.0045	0.0325	1.0000

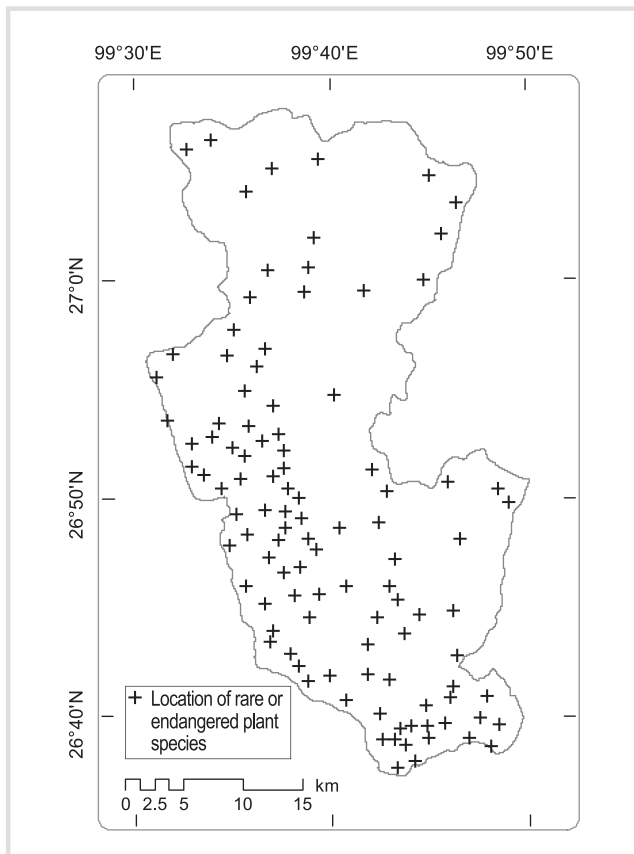
^{a)}Kappa index of agreement = 0.3159.

be accessed in less than half an hour, 35 sites (33%) can be accessed in 0.5–1 hour, and 13 sites (12.3%) can be accessed in 1–2 hours; only 4 sites (3.8%) need more than 2 hours to be reached.

Protection levels and access times for the rare and endangered species found in the study area are summarized in Table 2. Five species listed as endangered by the IUCN are found in the study area; their average access time varies from 0.27 to 0.89 hour. Three species

(*Torreya yunnanensis*, *Magnolia sieboldii*, and *Tricholoma matsutake*) have been identified as particularly vulnerable. They all can be reached within less than 1 hour of walking. Protection of these species should be given high priority.

A total of 25 other species have national or provincial importance. Most of them are endemic to northwest Yunnan; they occur in small geographical ranges and at low densities (Xu and Wilkes 2004; Yang et al 2004). Their average access time varies from 0.19 to 1.08 hour. Based on the short access time and the limited number of sites, 5 species (*Neocinnamomum mekongense*, *Picea brachytyla*, *Pseudotsuga forrestii*, *Anisadenia pubescens*, and *Trillium* spp) are especially vulnerable, which implies a need for active conservation management.

FIGURE 4 Location of rare or endangered plant species in the study area.

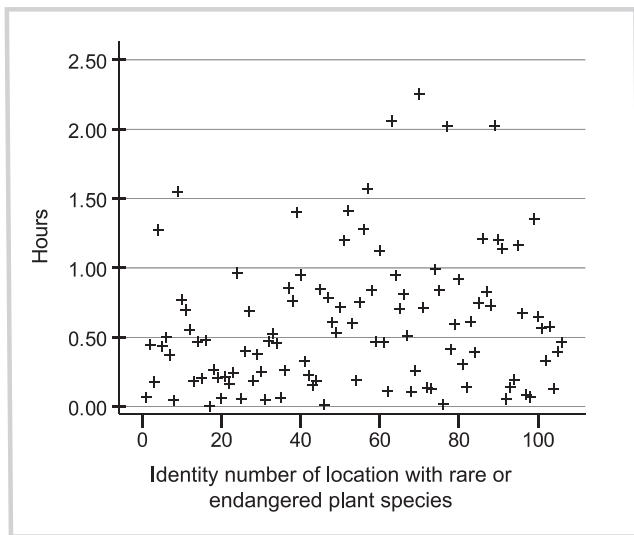
Discussion

Because of its dynamic nature, off-road tourist travel is difficult to measure and predict using standard monitoring methods such as surveys and counting and tracking techniques (Hammit and Cole 1998; Leung et al 2011). This article suggests an alternative method of estimating off-road use through time-based accessibility modeling with GRASS GIS. Based on the assumption that more accessible areas tend to be more frequently used by tourists, a spatial pattern of off-road use, and thus of the potential impacts of park tourism, can be predicted.

Compared to conventional estimation of accessibility by simple linear distances, the coupling of the *r.walk* module with a terrain model makes it possible to estimate walking time, and thus accessibility, more precisely. The *r.walk* module calculates time frames using the Naismith rule with Langmuir's adjustments to take into account vertical (uphill and downhill), as well as horizontal, distances (Carver and Wrightham 2007; Scarf 2007; Carver et al 2012). Therefore, the accessibility maps shown in Figures 2 and 3 suggest that difficult-to-access areas consist mostly of sites at high elevations (eg mountain peaks) or a long distance from roads or tracks.

As previously mentioned, the Naismith–Langmuir rule does not take into account variations in walkers' abilities,

FIGURE 5 Time required to access each location with rare or endangered plant species in the study area.



weather, or underfoot conditions. These factors may create additional time penalties. For example, wind direction or stability of ground material can influence walking speed significantly (Fritz and Carver 2000). Hence, the accessibility estimates produced by this study are based on optimal walking times.

A comparison between scenarios A and B suggests differences in access times for more than 68% of the area (Table 1). This highlights the importance of visitor management (park access restriction). Therefore, it is recommended that park managers consider the closure of tracks as a possible means of minimizing tourist use and related disturbances (Leung et al 2011; Wimpey and Marion 2011).

However, decisions about which tracks should be closed and when should be made with care, because closure may lead to new problems. For instance, the number of tourists may drop when tracks are closed because the park can offer fewer recreational opportunities (Wimpey and Marion 2011); thus, tourism revenues, which may be needed to fund conservation measures, may drop or become less reliable (Kiss 2004; Kruger 2005).

Another concern is the possibility that, when official tracks are closed, visitors may create informal tracks in remote, roadless areas (Marion and Leung 2004; Dumont et al 2005). Therefore, it is necessary to balance tourists' needs with the protection of resources in any track closure decision. Tourist routes should be as attractive as possible, to encourage tourists to remain on them while traversing more resilient sites and avoiding sensitive areas where rare or endangered species prevail, such as the southern and western parts of the study area (Figure 4).

Because of chronic underfunding, park conservation efforts and funding allocations need to be prioritized carefully, based in part on information about the threats from tourism. Off-road walking time to access sites, which

is one indication of potential threat, can supplement conventional biological justifications (eg rarity and endemic character as identified in the IUCN Red List and the national and provincial lists) in making conservation decisions (Mace et al 2008). Species that are vulnerable because they are easily accessed and occur infrequently will have a higher chance of survival if park managers refine their resource allocation based on this ranking (Wilson et al 2005; Halpern et al 2006; Pressey et al 2007).

However, the ranking in Table 2 is based on available data on rare and endangered species. It is unlikely that we have complete knowledge about the species and their geographical distribution (especially considering survey bias toward species near roads or tracks). If data collection continues, new species, or new locations for known species, might be identified within or near the park. It is necessary to adapt priorities as knowledge about biodiversity features changes over time (Wilhere 2002; McDonald-Madden et al 2010).

In addition to supporting priority setting, the accessibility data have a number of other applications relevant to biodiversity conservation and resource management. Examples include estimation of resource use by villagers, such as the size of the area in which herding or collection of non-timber forest products takes place (Ullah 2011), prediction of exotic species introduction by human activities (Potito and Beatty 2005), or design of management or planning zones for a variety of end uses, particularly for areas that are appropriate for low-impact tourism (Sabatini et al 2007; Esteves et al 2011). Accessibility data can also be used in search and rescue operations to map areas where lost tourists are more likely to be found (Heggie and Heggie 2009).

Some limitations to this study require attention if the use of accessibility data is to be expanded. The first relates to the uncertainty of the parameters used in Equation 1, which were derived from empirical tests in the Scottish Highlands; their applicability to other mountainous regions around the world, including the study area discussed in this article, has not been verified. High altitudes (~2000 m or more above sea level) affect human performance (eg walking speed) differently from lower altitudes because of differences in oxygen level and atmospheric pressure (Hoppeler and Vogt 2001; Muza 2007). Thus, there is a need to identify parameters for this study area (and similar regions around the Himalayas) that would enable more precise estimates of walking time. Time records from park rangers, tourist volunteers, and local mountaineering events might provide useful data for verifying and refining these parameters (Norman 2004; Scarf and Grehan 2005).

The second limitation is related to the use of a DEM, an important source of data on terrain attributes used in *r.walk* computation. Although the DEM used in this study has a reasonable spatial resolution (a cell size of 25 × 25 m) for mountain areas, this does not ensure high accuracy because of the rapid variation in terrain in the

TABLE 2 Species characteristics used to determine conservation priority in the study area.^{a)} (Table continued on next page.)

Species	Protection level ^{c)}			No. sites in access time class ^{b)}				Access time (h) (mean ± SD)
	R	N	P	T1	T2	T3	T4	
<i>Abies georgei</i>	VU		III	5	2	1	0	0.54 ± 0.45
<i>Anisadenia pubescens</i> ^{b)}			III	1	0	0	0	0.46
<i>Anisodus acutangulus</i>			III	3	2	1	1	0.82 ± 0.67
<i>Berneuxia thibetica</i>			III	1	1	0	1	1.03 ± 1.09
<i>Camellia yunnanensis</i>			III	0	1	0	0	0.95
<i>Cephalotaxus lanceolata</i>	VU	II		0	3	1	0	0.89 ± 0.45
<i>Cordyceps sinensis</i>		II		3	1	0	0	0.41 ± 0.34
<i>Cypripedium</i> sp		II		2	3	1	0	0.65 ± 0.37
<i>Dysosma veitchii</i>			III	1	1	2	0	0.99 ± 0.47
<i>Eriophyton wallichii</i>			III	0	1	0	0	0.61
<i>Fritillaria delavayi</i>			II	1	1	1	0	0.73 ± 0.62
<i>Glycyrrhiza yunnanensis</i>			III	0	1	0	0	0.71
<i>Hemsleya lijiangensis</i>			III	1	0	0	1	1.08 ± 1.37
<i>Magnolia sieboldii</i> ^{b)}	VU	II		2	1	0	0	0.51 ± 0.39
<i>Megacarpaea delavayi</i>			II	1	3	0	0	0.56 ± 0.38
<i>Neocinnamomum mekongense</i> ^{b)}			II	1	0	0	0	0.19
<i>Paraquilegia microphylla</i>			III	0	1	1	0	1.02 ± 0.37
<i>Phalaenopsis</i> sp		II		2	2	1	0	0.57 ± 0.43
<i>Picea brachytyla</i> ^{b)}		II		2	0	0	0	0.19 ± 0.04
<i>Pleione</i> sp		II		2	0	2	1	0.91 ± 0.84
<i>Polygonum cymosum</i>		II		0	1	0	0	0.57
<i>Psammosilene tunicoides</i>		II		2	1	0	0	0.42 ± 0.25
<i>Pseudotsuga forrestii</i> ^{b)}		II		5	0	0	0	0.27 ± 0.20
<i>Pterocarya delavayi</i>			III	2	2	0	0	0.42 ± 0.31
<i>Saussurea involucrate</i>			II	0	2	1	0	0.82 ± 0.34
<i>Taxus wallichiana</i>		I		7	1	1	0	0.39 ± 0.36
<i>Torreya yunnanensis</i> ^{b)}	EN	II		3	1	0	0	0.27 ± 0.21
<i>Tricholoma matsutake</i> ^{b)}	VU	II		3	2	0	0	0.40 ± 0.21
<i>Trillium</i> sp ^{b)}			III	1	0	0	0	0.47
<i>Triosteum himalayanum</i>			III	2	2	0	0	0.49 ± 0.49
Total	5	13	17	53	36	13	4	—
Average	—	—	—	—	—	—	—	0.59 ± 0.48

TABLE 2 Continued. (First part of Table 2 on previous page.)

^a)It is important to consider the unintended drawbacks of publishing information about the specific locations of rare and endangered species listed in this table: the park managers who contributed knowledge to this study were wary of publishing such information as they feared that it would encourage poaching.

^b)Species is more vulnerable to disturbance from off-road travel and needs a more active conservation management.

^c)R stands for IUCN Red List (EN = endangered; VU = vulnerable), N stands for the Chinese national protected list (I = first class; II = second class), and P stands for the Yunnan provincial protected list (II = second class; III = third class).

^d)T1: ≤0.5 hour, T2: 0.5–1.0 hour, T3: 1.0–2.0 hours, and T4: 2.0–3.2 hours.

study area and the errors and uncertainties inherent in creating this DEM based on topographic maps and traditional photogrammetric methods (Burrough and McDonnell 1998; Fisher and Tate 2006). Future work is planned to employ high-precision terrain models available for the study area, such as airborne interferometric synthetic aperture radar DEM data (Sun et al 2011), together with ground validation to reduce errors and uncertainties.

Finally, there is a limitation to the ability of the accessibility data to predict off-road uses. This study assumed that the probability of off-road travel depends entirely on the time cost (walking time) and did not account for the possibility that attractive landscape features might influence the behavior of off-road travel (Bishop and Lange 2005; de Aranzabal et al 2009). A useful next step would be to take attractive landscape features (eg peaks, lakes, wildlife, and forests) into account using recreation choice modeling (Termansen et al 2004; Bestard and Font 2009) to obtain a better estimate of off-road use of the park.

Conclusion

This paper shows that time-based accessibility modeling is useful to recognize the spatial pattern of tourist use in the study area, providing additional critical information about tourist use that traditional tourism monitoring techniques cannot easily offer. In particular, the application of the Naismith–Langmuir rule in the modeling offers an opportunity to more realistically measure accessibility in this mountainous park. The resulting accessibility information contributes to the development of more appropriate strategies for both tourism management (eg track closure or other restrictions) and resource conservation (eg protection of rare or endangered species). With further refinement, the method can be expanded to other mountainous protected areas in northwest Yunnan Province and elsewhere in the Himalayas, where effective monitoring of recreational uses and their impacts is needed to manage the rapid increase in nature-based tourism.

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REFERENCES

- Adriaensen F, Chardona JP, de Blust G, Swinnen E, Villalba S, Gulinck H, Matthysen E.** 2003. The application of “least-cost” modeling as a functional landscape model. *Landscape and Urban Planning* 64(4):233–247.
- Aitken R.** 1977. *Wilderness Areas in Scotland* [PhD dissertation]. Aberdeen, United Kingdom: University of Aberdeen.
- Balmford A, Beresford J, Green J, Naidoo R, Walpole M, Manica A.** 2009. A global perspective on trends in nature-based tourism. *PLoS Biology* 7(6): e1000144. <http://dx.doi.org/10.1371/journal.pbio.1000144>.
- Bestard AB, Font AR.** 2009. Environmental diversity in recreational choice modelling. *Ecological Economics* 68(11):2743–2750.
- Bishop ID, Lange E.** 2005. *Visualization in Landscape and Environmental Planning: Technology and Applications*. London, United Kingdom: Taylor & Francis.
- Buntaine MT, Mullen RB, Lassoie JP.** 2007. Human use and conservation planning in alpine areas of northwestern Yunnan, China. *Environment, Development and Sustainability* 9(3):305–324.
- Burrough PA, McDonnell RA.** 1998. *Principles of Geographical Information Systems*. Oxford, United Kingdom: Oxford University Press.
- Carver S, Comber A, McMorrin R, Nutter S.** 2012. A GIS model for mapping spatial patterns and distribution of wild land in Scotland. *Landscape and Urban Planning* 104(3–4):395–409.
- Carver S, Fritz S.** 1999. Mapping remote areas using GIS. In: Usher MB, editor. *Landscape Character: Perspectives on Management and Change*. Natural Heritage of Scotland Series, No. 8. Norwich, United Kingdom: Stationery Office, pp 26–34.
- Carver S, Wrightham M.** 2007. Shrinking wild lands: Assessing human intrusion in the highlands of Scotland, 1870 to 2004, using geographical information systems. In: Watson A, Sproull J, Dean L, editors. *Science and Stewardship to Protect and Sustain Wilderness Values: Eighth World Wilderness Congress Symposium*. Fort Collins, CO: Department of Agriculture, Forest Service, Rocky Mountain Research Station, pp 357–366.
- Cessford G, Muhar A.** 2003. Monitoring options for visitor numbers in national parks and natural areas. *Journal for Nature Conservation* 11(4):240–250.
- Collischonn W, Pilar JV.** 2000. A direction dependent least-cost-path algorithm for roads and canals. *International Journal of Geographical Information Science* 14(4):397–406.
- Cope A, Doxford D, Probert C.** 2000. Monitoring visitors to United Kingdom countryside resources: The approaches of land and recreation resource management organisations to visitor monitoring. *Land Use Policy* 17(1): 59–66.
- D’Antonio A, Monz C, Lawson S, Newman P, Pettebone D, Courtemanch A.** 2010. GPS-based measurements of backcountry visitors in parks and protected areas: Examples of methods and applications from three case studies. *Journal of Park and Recreation Administration* 28(3):42–60.
- de Aranzabal I, Schmitz MF, Pineda FD.** 2009. Integrating landscape analysis and planning: A multi-scale approach for oriented management of tourist recreation. *Environmental Management* 44(5):938–951.

- Dumont B, Roovers P, Gulincx H.** 2005. Estimation of off-track visits in a nature reserve: A case study in central Belgium. *Landscape and Urban Planning* 71(2-4):311-321.
- Eagles PFJ, Cool SFM.** 2002. *Tourism in National Parks and Protected Areas: Planning and Management*. Oxon, United Kingdom: CABI.
- Eastman JR, Jin W, Kyem PAK, Toledano J.** 1995. Raster procedures for multi-criteria/multi-objective decisions. *Photogrammetric Engineering & Remote Sensing* 61(5):539-547.
- English DBK, Kocis MS, Zarnoch SJ.** 2004. Characteristics and use patterns of visitors to dispersed areas of urban national forests. In: Sievanen T, Erkkonen J, Jokimaki J, Saarinen J, Tuulentie S, Virtanen E, editors. *Policies, Methods and Tools for Visitor Management*. Proceedings of the Second International Conference on Monitoring and Management of Visitor Flows in Recreational and Protected Areas. Rovaniemi, Finland: Finnish Forest Research Institute, 16-20 June, pp 179-184.
- Esteves CF, Ferraz SFD, Ferraz K, Galetti M, Theobald DM.** 2011. Human accessibility modelling applied to protected areas management. *Natureza & Conservacao* 9(2):232-239.
- Fisher PE, Tate NJ.** 2006. Causes and consequences of error in digital elevation models. *Progress in Physical Geography* 30(4):467-489.
- Fritz S, Carver S.** 2000. Modelling remoteness in roadless areas using GIS. In: Parks BO, Clarke KM, Crane MP, editors. *Problems, Prospects and Research Needs*. Proceedings of 4th International Conference on Integrating GIS and Environmental Modelling (GIS/EM4). Alberta, Canada, 2-8 September, No. 157.
- Ganskopp D.** 2000. Least-effort pathways: A GIS analysis of livestock trails in rugged terrain. *Applied Animal Behavior Science* 68(2):179-190.
- Halpern BS, Pyke CR, Fox HE, Haney JC, Schlaepfer MA, Zaradic P.** 2006. Gaps and mismatches between global conservation priorities and spending. *Conservation Biology* 20(1):56-64.
- Hammit WE, Cole DN.** 1998. *Wildland Recreation: Ecology and Management*. 2nd edition. New York, NY: Wiley.
- Heggie TW, Heggie TM.** 2009. Search and rescue trends associated with recreational travel in US national parks. *Journal of Travel Medicine* 16(1):23-27.
- Hoppeler H, Vogt M.** 2001. Muscle tissue adaptations to hypoxia. *Journal of Experimental Biology* 204(18):3133-3139.
- Hornback KE, Eagles PFJ.** 1999. *Guidelines for Public Use Measurement and Reporting at Parks and Protected Areas*. Gland, Switzerland: World Commission on Protected Areas.
- Karanth KK, DeFries R.** 2011. Nature-based tourism in Indian protected areas: New challenges for park management. *Conservation Letters* 4(2):137-149.
- Kiss A.** 2004. Is community-based ecotourism a good use of biodiversity conservation funds? *Trends in Ecology & Evolution* 19(5):232-237.
- Kruger O.** 2005. The role of ecotourism in conservation: Panacea or Pandora's box? *Biodiversity and Conservation* 14(3):579-600.
- Langmuir E.** 1984. *Mountaineering and Leadership*. Manchester, United Kingdom: British Mountaineering Council.
- Leung YT, Newburger T, Jones M.** 2011. Developing a monitoring protocol for visitor-created informal trails in Yosemite National Park, USA. *Environmental Management* 47(1):93-106.
- Li HL, Li DH, Li T, Qiao Q, Yang J, Zhang HM.** 2010. Application of least-cost path model to identify a giant panda dispersal corridor network after the Wenchuan earthquake: Case study of Wolong Nature Reserve in China. *Ecological Modelling* 221(6):944-952.
- Li MM, Wu BH, Cai LP.** 2008. Tourism development of World Heritage Sites in China: A geographic perspective. *Tourism Management* 29(2):308-319.
- Mace GM, Collar NJ, Gaston KJ, Hilton-Taylor C, Akcakaya HR, Leader-Williams N, Milner-Gulland EJ, Stuart SN.** 2008. Quantification of extinction risk: IUCN's system for classifying threatened species. *Conservation Biology* 22(6):1424-1442.
- Marion JL, Leung YT.** 2004. Environmentally sustainable trail management. In: Buckley R, editor. *Environmental Impact of Ecotourism*. Cambridge, MA: CABI, pp 229-243.
- Mayer M, Mueller M, Woltering M, Arnegger J, Job H.** 2010. The economic impact of tourism in six German national parks. *Landscape and Urban Planning* 97(2):73-82.
- McDonald-Madden E, Probert WJM, Hauser CE, Runge MC, Possingham HP, Jones ME, Moore JL, Rout TM, Vesik PA, Wintle BA.** 2010. Active adaptive conservation of threatened species in the face of uncertainty. *Ecological Applications* 20(5):1476-1489.
- Mitasova H, Neteler M.** 2004. GRASS as open source free software GIS: Accomplishments and perspectives. *Transactions in GIS* 8(2):145-154.
- Muza SR.** 2007. Military applications of hypoxic training for high-altitude operations. *Medicine and Science in Sports and Exercise* 39(9):1625-1631.
- Neteler M, Bowman MH, Landa M, Metz M.** 2012. GRASS GIS: A multi-purpose open source GIS. *Environmental Modelling & Software* 31(1):124-130.
- Neteler M, Mitasova H.** 2008. *Open Source GIS: A GRASS GIS Approach*. 3rd edition. New York, NY: Springer.
- Newsome D, Moore SA, Dowling RK.** 2002. *Natural Area Tourism: Ecology, Impacts and Management*. Bristol, United Kingdom: Channel View.
- Nikolakaki P.** 2004. A GIS site-selection process for habitat creation: Estimating connectivity of habitat patches. *Landscape and Urban Planning* 68(1):77-94.
- Norman JM.** 2004. Running uphill: Energy needs and Naismith's rule. *Journal of the Operational Research Society* 55(3):308-311.
- Nyaupane GP, Poudel S.** 2011. Linkages among biodiversity, livelihood, and tourism. *Annals of Tourism Research* 38(4):1344-1366.
- Pettebone D.** 2009. *Quantifying and Modelling Visitor Use in Yosemite National Park and Rocky Mountain National Park* [PhD dissertation]. Fort Collins, CO: Colorado State University.
- Pickering C, Hill W.** 2007. Impacts of recreation and tourism on plant biodiversity and vegetation in protected areas in Australia. *Journal of Environmental Management* 85(4):791-800.
- Pickering C, Mount A.** 2010. Do tourists disperse weed seed? A global review of unintentional human-mediated terrestrial seed dispersal on clothing, vehicles and horses. *Journal of Sustainable Tourism* 18(2):239-256.
- Pontius RG.** 2000. Quantification error versus location error in comparison of categorical maps. *Photogrammetric Engineering & Remote Sensing* 66(8):1011-1016.
- Potito AP, Beatty SW.** 2005. Impacts of recreation trails on exotic and ruderal species distribution in grassland areas along the Colorado front range. *Environmental Management* 36(2):230-236.
- Pressey RL, Cabeza M, Watts ME, Cowling RM, Wilson KA.** 2007. Conservation planning in a changing world. *Trends in Ecology & Evolution* 22(11):583-592.
- Rai SC, Sundriyal RC.** 1997. Tourism and biodiversity conservation: The Sikkim Himalaya. *Ambio: A Journal of the Human Environment* 26(4):235-242.
- Ray N, Ebener S.** 2008. AccessMed 3.0: Computing geographic coverage and accessibility to health care services using anisotropic movement of patients. *International Journal of Health Geographics* 7(1):63-80.
- Saayman M, Saayman A.** 2006. Estimating the economic contribution of visitor spending in the Kruger National Park to the regional economy. *Journal of Sustainable Tourism* 14(1):67-81.
- Sabatini MD, Verdiell A, Iglesias RMR, Vidal M.** 2007. A quantitative method for zoning of protected areas and its spatial ecological implications. *Journal of Environmental Management* 83(2):198-206.
- Scarf P.** 2007. Route choice in mountain navigation, Naismith's rule, and the equivalence of distance and climb. *Journal of Sports Science* 25(6):719-726.
- Scarf P, Grehan P.** 2005. An empirical basis for route choice in cycling. *Journal of Sports Sciences* 23(9):919-925.
- Shoval N, Isaacson M.** 2010. *Tourist Mobility and Advanced Tracking Technologies*. New York, NY: Routledge.
- Skov-Petersen H, Gimblett R.** 2008. Introduction: Monitoring, simulation and management of visitor landscape. In: Gimblett R, Skov-Petersen H, editors. *Monitoring, Simulation and Management of Visitor Landscapes*. Tucson, AZ: University of Arizona Press, pp 1-12.
- Sun D, Walsh D.** 1998. Review of studies on environmental impacts of recreation and tourism in Australia. *Journal of Environmental Management* 53(4):323-338.
- Sun Z, Guo H, Li XW, Yue XJ, Huang QN.** 2011. DEM generation and error analysis using the first Chinese airborne dual-antenna interferometric SAR data. *International Journal of Remote Sensing* 32(23):8485-8504.
- Termansen M, McClean CJ, Skov-Petersen H.** 2004. Recreational site choice modelling using high-resolution spatial data. *Environment and Planning A* 36(6):1085-1099.
- Tomczyk AM.** 2011. A GIS assessment and modelling of environmental sensitivity of recreational trails: The case of Gorce National Park, Poland. *Applied Geography* 31(1):339-351.
- Ullah IIT.** 2011. A GIS method for assessing the zone of human-environmental impact around archaeological sites: A test case from the Late Neolithic of Wadi Ziqlab, Jordan. *Journal of Archaeological Science* 38(3):623-632.
- van Vliet J, Bregt AK, Hagen-Zanker A.** 2011. Revisiting kappa to account for change in the accuracy assessment of land-use change models. *Ecological Modelling* 222(8):1367-1375.
- Wilhere GF.** 2002. Adaptive management in habitat conservation plans. *Conservation Biology* 16(1):20-29.
- Wilson K, Pressey RL, Newton A, Burgman M, Possingham H, Weston C.** 2005. Measuring and incorporating vulnerability into conservation planning. *Environmental Management* 35(5):527-543.
- Wimpey J, Marion JL.** 2011. A spatial exploration of informal trail networks within Great Falls Park, VA. *Journal of Environmental Management* 92(3):1012-1022.

Xia JH, Arrowsmith CA. 2008. Techniques for counting and tracking the spatial and temporal movement of visitors. In: Gimblett R, Skov-Petersen H, editors. *Monitoring, Simulation and Management of Visitor Landscapes*. Tucson, AZ: University of Arizona Press, pp 85–105.

Xu JC, Wilkes A. 2004. Biodiversity impact analysis in northwest Yunnan, Southwest China. *Biodiversity and Conservation* 13(5):959–983.

Yang YM, Tian K, Hao JM, Peng SJ, Yang YX. 2004. Biodiversity and biodiversity conservation in Yunnan, China. *Biodiversity and Conservation* 13(5):813–826.

Zhong LS, Deng JY, Song ZW, Ding PY. 2011. Research on environmental impacts of tourism in China: Progress and prospect. *Journal of Environmental Management* 92(11):2972–2983.

Zhou DQ, Grumbine RE. 2011. National parks in China: Experiments with protecting nature and human livelihoods in Yunnan Province, People's Republic of China (PRC). *Biological Conservation* 144(5):1314–1321.

Zinda JA. 2012. Hazards of collaboration: Local state co-optation of a new protected-area model in Southwest China. *Society & Natural Resources* 25(4):384–399.