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*Original Research*

# Ecological Carrying Capacity and Ecological Footprint of Ski Tourism: A Case of North Slope Region of Tianshan Mountain

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**Abstract**

The ski industry in China has been entering into a phase of rapid development, since the beginning of Beijing 2022 Winter Olympics, with the typical distribution characteristics of ski tourism in main snow-ice resources area. The North Slope region of the Tianshan Mountain contains the favorable endowment of ski resources in China and has become one of the best tourist destinations. However, ski tourism are facing a significant challenge in ecological and environmental protection. Few China Ski tourism studies considered the discussion of ecological footprint. Therefore, this study aims to explore an ecological accounting scheme for ski tourism, based on evaluating the local ecological carrying capacity and ecological pressure, and to examine the sustainability of the regional ski industry layout, took a representative Tianshan ski tourist city as the research case. It is indicated that the ecological footprint of ski resorts are considerably larger than that of other tourism activities, which highlights the urgent need to manage ecological issues of ski resorts. The regional tourist attractions cannot match ski tourism endowment. Nalati ski resorts presents a state of ecological deficit, as the largest tourism area in North Slope region of Tianshan Mountain. Ski tourism accommodations contribute to the largest proportion of the ecological footprint. Fundamentally, this study offers an industry ecological model consideration based on ski tourism sustainability assessment.

**Keywords**: ski tourism, sustainable development, ecological carrying capacity, ecological footprint

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## Introduction

Since the emergence of international mass tourism in the 1970s, contemporary ski tourism has been developing rapidly. At present, several famous ski resort belts have been basically formed in the world, such as in the European Alps, North America, Eastern Europe, Western Europe, Central Asia, and East Asia. These tourist destinations are representatives of the ski industry in different regions [1]. Ski tourism has been one of the most popular recreation activities, simultaneously bringing about major economic benefits and employment increase, especially in mountainous areas. With its direct dependence on natural resources, snow-based tourism was the first tourism market examined for its climate change risk and ecological carrying capacity [2] Therefore, the ecological environment is one of the most important factors for ski tourism.

China, with diverse terrain and abundant skiing resources, has the potential to develop ski tourism industry. The successful hosting of the Winter Olympic Games and the Winter Paralympic Games in 2022 has contributed to the rapid growth of China's ski sports industry as well as the efficient release of the market's potential. Additionally, the ski industry in China is still in the initial development stage, with rapidly growing market demand. A series of ecological problems may arise with the increasing exploit of skiing resources, such as the loss of water and soil resources, land desertification and others. Therefore, it is urgently indispensable to balance the development of China's ski tourism industry with the protection of ecological environment in ski tourism areas.

China's the Silk Road Economic Belt and the 21st-Century Maritime Silk Road Initiative has provided a channel of international cooperation. And the North Slope region of the Tianshan Mountain is located in a significant intersection of the Silk Road Economic Belt, which could be supported by the government. The urbanization development level, economic development level and population density of the North Slope region of Tianshan Mountain are at a relatively high level in northwest China. Additionally, there are abundant natural and cultural tourism resources, especially skiing resources.

The North Slope region of the Tianshan Mountain is one of the best endowed regions for ski tourism resources in China, the others are Jilin, Heilongjiang and Altai regions. Besides, Consecutive years of sufficient snowfall have brought the ski resources of the North Slope region of the Tianshan Mountain to a higher level. While in the same time, ski destinations in the Alps, France, Austria, and some other countries faced the climate challenges and about half of the ski resorts met sharp decline in 2022 [3], left an opportunity to the North Slope region of Tianshan Mountain to occupy the international market. On the other hand, the ecology of Tianshan Mountain faces problems like soil erosion, desertification, and land salinization, which could have a detrimental effect on the development of ski tourism industry [4, 5]. And the ecological damage caused by the development of ski tourism would in turn affect the development of the ski industry. Ecological management problems in the local ski industry should be solved before it becomes more severe.

Increasing researches focused on the sustainable development of skiing resources and the ecology of the ski industry, especially the relationship between the ski industry and the environment [6]. The ski tourism is a type of resource-based industry, depending on both ski resources and the natural environment, especially the climate environment. Over-exploitation of the resources might result in increased ecological damages, including vegetation loss, soil erosion, water resource depletion, and unnatural changes to the local climate [7, 8]. Therefore, adaptation strategies to cope with the effect of a varying climate is one of the most prominent topics [9-13]. Abegg et al. designed a list of indicators with technical details, and used it to evaluate the snow conditions for ski tourism [14].Scott et al. present an integrated model with recommendations for adapting to climate change on both the supply and demand side of the ski tourism market [15]. Another crucial topic is balancing the economic benefits of tourism with the environmental preservation [16-18]. Annemarie et al have successfully created an intelligent skiing model, thereby providing a theoretical basis for the intelligent development of ski tourism [19]. The humanistic perspective of ski tourism is emerging, and some scholars have begun to pay attention to tourists' perception of ski tourism [20-22]. Shang et al studied experience attributes ski tourism from the perspectives of resource user based on 14 ski resorts [23].

Overall, the existing literature has not focus enough attention to the ecological development of ski tourism. In particular, there is a lack of research on the ecological carrying capacity and ecological footprint of ski tourism. In particular, China's ski tourism industry is facing serious environmental challenges, including unbalanced industrial structure and inappropriate natural resource development [24]. Besides, few China ski tourism studies involved the industry ecology and the related policymaking and the perspective of ecological footprint, the ecological carrying capacity and ecological footprint of ski tourism in China. Therefore, this study concentrates on the ecological pressure of the ski tourism industry on the representative North Slope region of Tianshan Mountain, and explores the relationship between the local industrial distribution and ecological carrying capacity. This endeavor is of global significance. It is also the intrinsic concern of environmentally-developing nexus in the prospective of ski tourism growth.

The following sections of the paper are organized as follows: Section 2 provides an overview of the methodology and data sources employed in this study. Then, the third section illustrates the results and offers a detailed analysis of the findings obtained from the kernel density estimation, ecological footprint accounting, and ecological carrying capacity accounting. Additionally, this section explores the implications of the results for policy. Finally, the main conclusions are provided in Section 5.

## Material and Methods

### Study Area

The North Slope region of the Tianshan Mountain is located in Xinjiang, China, from 42°78′-45°59′N to 84°33′-90°32′E. This region and Jilin Changbai Mountain region contain the most endowment of ski tourism resources in China. In contrast with Jilin development of ski industry, the ski tourism is still in its infancy stage in most areas of the North Slope region of the Tianshan Mountain. However, at so a significant ski resource endowment area, there have been only a few available statistical data and few study until now. Ili city, located in the North Slope region of the Tianshan Mountain, is one of the most suitable areas for the development of ski tourism, involving the distinctive layered geomorphological features of three mountains and two valleys. The area with snowfall greater than 150 mm in Ili city covers about 2,100 square kilometers, accounting for 3.7% of the total city area. The greater the vertical drop, the larger and higher quality ski resort area can be constructed. The area with a vertical drop greater than 800 meters is 25,529,000 square kilometers, accounting for 45.19% of the total area of city. Ili has been the most important and typical ski tourism zone in the North Slope region of the Tianshan Mountain. Nalati International ski resort and Yilegedai ski resort, with a full range of ski touring facilities, are the only two 4S-level ski resorts in Ili. These two ski resorts served the majority of ski tourists. The data from these two resorts can basically represents the volume of the regional ski tourism footprint. And, there are numerous ecological issues with the rapid growth of ski tourism in Ili, including land desertification, salinization, and severe soil erosion [25, 26]. Moreover, the construction and operation of ski resorts have been causing more and further exacerbated ecological problems.

### Methods

#### *Ski Tourism Ecological Footprint*

Ecological Footprint accounting was designed to represent human consumption of biological resources and generation of wastes in terms of appropriated ecosystem area, which can be compared to the biosphere's productive capacity in a given year [27] And the Ski Tourism Ecological Footprint (STEF) is an application of the ecological footprint in tourism industry. It measures tourists' consumption of biological resources and generation of wastes during their activities [28]. There are two primary approaches commonly used to measure the ecological footprint: the component approach and the integrated approach. Among them, the integrated approach requires the collection of per capita consumption data through questionnaires to calculate the ecological footprint on a small scale [29]. The component approach relies on statistical data to obtain per capita consumption information based on regional consumption and population, and to calculate the ecological footprint on a large scale [30].

Calculating the tourism ecological footprint requires separate statistics on resource consumption and waste emissions generated by tourist activities, such as eating, sightseeing, shopping and entertainment involved in tourism. This requires establishing six ecological footprint accounts for tourism catering, accommodation, transportation, sightseeing, shopping, and entertainment. However, the ski tourism industry mainly provides travel experiences rather than products. Consequently, tourists' travel and shopping behavior might have a little impact on the environment, so this study does not consider the ecological footprint of shopping activities in ski tourism. Additionally, programs in ski resorts for sightseeing consumes almost no energy. Hence, this study constructed a combined ecological footprint account merging ski tourism sightseeing and entertainment. So, this study establishes four ecological footprint accounts, including the Ski Entertainment Ecological Footprint Account, Ski Catering Ecological Footprint Account, Ski Transportation Ecological Footprint Account, Ski accommodation Ecological Footprint Account. The formulas of the regional ski tourism ecological footprint are as follows.

The Total Ski Tourism Ecological Footprint.

$$STEF = \sum_{i=1}^{4} STEF_i \tag{1}$$

In this formula, the *STEFi* represents the ecological footprint of various types of ski tourism ecological footprint.

The Entertainment Ski Tourism Ecological Footprint.

$$STEF_{ent} = \sum S_i \times r_i \tag{2}$$

The Entertainment Ski Tourism Ecological Footprint refers to the area of land for biological production necessary for the consumption of various resources and waste absorption related to sightseeing, leisure and recreation. $S_i$ is the area occupied by each ski tourism and entertainment venue, and $r_i$ is the equivalence coefficient of the built-up area.

The Transportation Ski Tourism Ecological Footprint.

$$STEF_{tra} = \sum S_i \times R_i \times r_i + \sum N_j \times D_j \times C_j / m \times r_j \tag{3}$$

The ecological footprint of ski tourism for transportation refers to the area of biological production land necessary for the consumption of various resources and waste absorption related to tourism transportation, which is composed of two parts: the ecological footprint of tourism transportation facilities and the ecological footprint generated by tourists arriving at tourist places. The calculation is divided into the area of the parking lot of each ski resort and the energy consumption generated by tourists using transportation. In the formula: $S_i$ represent the area of transportation facilities, $R_i$ represent the frequency of use of class $i$ transportation facilities, $N_j$ represent the number of tourists received by the ski resort, $D_j$ represent the distance between the ski resort and the town, $C_j$ represent the energy consumption per unit distance, m is the average calorific value of fossil energy, and $r_i$ and $r_j$ are the equivalence coefficients of built-up area and fossil energy land equivalence coefficient respectively.

The Catering Ski Tourism Ecological Footprint.

$$STEF_{food} = \sum S_i \times r_i + \sum N \times D \times C_j / P_j \times r_j \quad (4)$$

The ecological footprint of ski tourism catering refers to the area of biological production land necessary for the consumption of various resources and the absorption of waste related to tourists' catering, which is composed of three parts: the built-up area of catering institutions, the land area converted from food consumption during tourists' tourism, and the land area converted from fossil energy consumed in providing catering services. Since the energy consumed in the production of catering products is relatively small, it is ignored. In the formula: $S_i$ is the built-up area of catering establishments, $N$ is the number of tourists, $D$ is the average number of days traveled by ski tourists, $C_j$ is the average daily consumption of each class of food by tourists, $P_j$ is the productivity of land for the production of Class $j$ food, $E_k$ is the corresponding production land area converted into $k$ energy consumption, and $r$ is the equivalence coefficient of corresponding biological production land.

The Accommodation Ski Tourism Ecological Footprint.

$$STEF_{ac} = \sum N_i \times S_i \times r_i + \sum 365 \times N_j \times K_j \times C_j / m \times r_j \quad (5)$$

The ecological footprint of ski tourism accommodation refers to the area of biological production land necessary for various resource consumption and waste absorption related to the tourists' accommodation, which is composed of the built-up area of accommodation institutions and the area of energy consumption conversion land. In the formula: $N_i$ is the number of beds, $S_i$ is the area of built-up area corresponding to the unit bed, $Ki$ is the average occupancy rate of beds for accommodation institutions, $C_i$ is the energy consumption per bed, $m$ is the average calorific value of fossil fuels, $r_i$ is the equivalence coefficient of the built-up area, and $r_j$ is the equivalence coefficient of fossil energy.

*Ecological Carrying Capacity and Ecological Surplus/Ecological Deficit of Ski Tourism*

The ecological carrying capacity of any defined area represents the maximum amount of goods and environmental services that could be produced, in a sustainable way, according to the land use of that area [31]. To determine the Ski Tourism Ecological Carrying Capacity (STECC), it's necessary to establish an STECC account of the area of local arable land, forest land, construction land, fossil energy land, grassland, and water area. First, the obtained data are multiplied by the equivalence coefficient and production coefficient of each type of resources. The processed data is the average ecological carrying capacity after been standardization. Then, the ecological carrying capacity of different resources were summarized to find the total local tourism ecological carrying capacity [32].

The difference value between the ecological footprint of tourism and the ecological carrying capacity of tourism is the total ecological deficit or surplus. That can reflect the regional ecological capacity and are critical indicators to measure the ecological sustainability of the regional development. When TED>0, the region is in a state of ecological surplus and when TED<0, the region is in a state of ecological deficit [33]. The formula for calculating TED is as follows.

$$TED = TEF - TEC \quad (6)$$

*Kernel Density Estimation*

The method of Kernel Density Estimation (KDE) enables, this study to assess the clustering of attractions and the distribution of ski resorts in Ili. This allows identify opportunities for optimizing the spatial layout of the ski tourism industry in the region. Additionally, analyzing the ecological footprint of tourist activities helps identify areas with the highest ecological carrying capacity consumption. By combining these two methods, the potential ecological issues that may arise from an unreasonable spatial layout can be identified. This approach can be instrumental in assessing the ecological rationality of the local industrial layout and seek for a more sustainable tourism industry.

The study aims to evaluate the spatial clustering of tourist attractions in Ili Prefecture, compare it with the distribution of ski resorts in the same region, and ultimately identify ways to optimize the spatial layout of the regional ski tourism industry.

$$f(x) = \frac{1}{nh} \sum_{i=1}^{n} k[\frac{d(x - x_i)}{h}] \quad (7)$$

Table 1. Standard parameters of equivalence coefficient and production coefficient.

| Land type | Equivalence coefficient | Production coefficient |
|---|---|---|
| Fossil energy land | 1.1 | 0 |
| cultivated land | 2.8 | 2 |
| grassland | 0.5 | 0.2 |
| woodland | 1.1 | 0.9 |
| Built ground | 2.8 | 2.2 |
| waters | 0.2 | 1 |

where *f(x)* represents the estimated kernel density value, *n* refers to the number of scenic spots, *h* means the bandwidth, *k(x)* depicts the kernel function, *x* is the estimated point, $x_i$ donates the observation point, and $d(x - x_i)$ describes the estimated distance from the point *x* to the observation point $x_i$.

### *Data Sources*

This study draws its data from two sources. First, POI (Point of Interest) data for the kernel density estimation was collected from the Planning Cloud website (www.guihuayun.com). Second, the data of the ski resorts are used in the calculation of the ecological footprint. The statistical data are mainly obtained from Xinjiang Statistical Yearbook and Ili Economic and Social Development Statistical Bulletin. To measure the ecological footprint and carrying capacity of the ski resorts, the research team relied on survey data provided by the agencies both the urban tourism government and the ski resorts management committee. Then, the Ecological Footprint measurement also incorporates several standard data sets that include the yield and equivalence factors of various biological production areas, the per capita energy consumption of per unit of transportation distance et al. In addition, the Ecological Footprint measurement also uses standard data sets that include the production coefficients and equivalence coefficients of various biological production areas et al. The above parameters refer to the data published by FAO (Food and Agriculture Organization, www.fao.org) and WWF (World Wide Fund for Nature, wwf.panda.org). The following table shows the standard parameters of the equivalence coefficient or production c

## Results and Discussion

This section gives the estimation results of the systematic ecological footprint and ecological carrying capacity of regional ski tourism, combined with the distribution characteristics of tourism resources and the industry.

### Ecological Footprint Accounting of Ski Tourism

This study calculated the ecological footprint of Nalati ski resort and Yilegedai ski resort. With nearly all kinds of necessary ski touring facilities, the two ski resorts are the only two 4S-level ski resorts in Ili. And the two ski resorts provided service to the majority visitors to Ili, can basically represents the ecological footprint of Ili city. The ecological footprint accounts of ski tourism in Nalati International Ski Resort in Xinyuan County and Yilegedai Ski Resort in Gongliu County were combined to obtain the total ecological footprint accounts of ski tourism, as shown in Table 2. The following table summarizes the ecological footprint of ski tourism in the two major ski resorts.

#### *Ecological Footprint of Sightseeing, Entertainment in Ski Tourism*

The ecological footprints of sightseeing and entertainment are calculated according to the facilities of tourists' sightseeing and entertainment needs in the ski resorts. It consists of the infrastructure area supporting tourism-related activities and the area of fossil energy land required to ensure the normal operation of sightseeing and entertainment facilities. Therefore, in this study, an ecological footprint account (EFA) for ski sightseeing and entertainment is established to calculate the ecological footprint of ski tourism sightseeing and entertainment. Specifically, this account includes the area of ski entertainment and supporting service

Table 2. Summary of Ski Tourism Ecological Footprint.

| Snow Tourism Ecological Footprint | Nalati International Ski Resort | Yilegedai Ski Resort | Ski Tourism Ecological Footprint $hm^2$ | Percentage |
|---|---|---|---|---|
| Sightseeing and entertainment, ecological footprint/$hm^2$ | 84.84 | 84.56 | 169.40 | 11.19% |
| Transportation ecological footprint/$hm^2$ | 0.89 | 0.35 | 1.24 | 0.08% |
| Catering ecological footprint/$hm^2$ | 13.17 | 3.20 | 16.37 | 1.08% |
| Accommodation ecological footprint/$hm^2$ | 1040.78 | 286.63 | 1327.41 | 87.65% |
| Total ecological footprint /$hm^2$ | 1139.68 | 374.74 | 1514.42 | 100% |
| Average ecological footprint $10^{-2}$/$hm^2$ | 8.90 | 2.93 | 11.83 | |

Table 3. Ski Sightseeing and Entertainment Ecological Footprint Account.

| Ski Resort | Floor space (hm$^2$) | Type of land | Equivalence coefficient | Reception of tourists (10,000 people) | Ski Tourism Entertainment Ecological Footprint (hm$^2$) |
|---|---|---|---|---|---|
| Nalati International Ski Resort | 30.3 | Built-up area | 2.8 | 1.03 | 84.84 |
| Yilegedai Ski Resort | 30.2 | Built-up area | 2.8 | 0.25 | 84.56 |

facilities (ski slopes, snow parks, ski service halls, conveyor belts, sightseeing trails) and the area of fossil energy required to ensure the normal operation of ski entertainment facilities for energy consumption and waste absorption. The energy consumption and waste emissions generated by the normal operation of ski and leisure facilities can be negligible. The ecological footprint of ski tourism sightseeing and entertainment is 169.4hm$^2$. The following table shows the calculation of the ecological footprint of ski sightseeing and entertainment.

*Ecological Footprint of Transportation in Ski Tourism*

In this study, the base map used to measure the area of two ski resorts of Nalati International Ski Resort is served by a comprehensive geographic information service website created by the Chinese Platform for Common Geospatial Information Services (www.tianditu.gov.cn). The survey indicates that the parking area of Nalati International Ski Resort is about 8800 m$^2$. Here, the parking area of Yilegedai Ski Resort is tiny, is not taken into the account. Since there is a five months snow season in Ili, the parking area utilization rate is taken to be 35%.The ecological footprint of the transport facilities is 0.8624 hm$^2$. Both resorts are located near the national level road, and tourists' main means of travel is by car. The ecological footprint of ski tourism traffic is about 2.0991 hm$^2$. The following table shows the calculation results of the ecological footprint of tourism transport.

*Ecological Footprint of Catering in Ski Tourism*

In this study, the catering establishments of Nalati International Ski Resort are distributed outside the ski service hall with about 1000m$^2$. The catering established in Yilegedai Ski Resort are mainly located in the ski service hall. The ecological footprint of the built-up area of the catering facilities is about 0.28 hm$^2$. The food consumption of tourists is calculated concerning the food consumption data of urban residents in the Report on Economic and Social Development Achievements for the 70th Anniversary of P. R. China. (www.gov.cn/xinwen/2019-08/09/content_5420006.htm). The ecological footprint number of food

Table 4. Ski Tourism Transportation Ecological Footprint Account.

| Ski Resorts | Distance from town /km | Reception of tourists (10,000 people) | Energy consumption per unit distance 10-4GJ/km | Fossil energy has an average calorific value GJ/km | Equivalence coefficient | Ski tourism transportation ecological footprint (hm$^2$) |
|---|---|---|---|---|---|---|
| Nalati International Ski Resort | 8 | 1.03 | 9.1 | 93 | 1.1 | 0.89 |
| Yilegedai Ski Resort | 13 | 0.25 | 9.1 | 93 | 1.1 | 0.35 |

Table 5. Ski Tourism Catering Ecological Footprint Account.

| Types of food | Reception of tourists (10,000 people) | Per capita consumption (kg/per/d) | Average number of days for tourists | Corresponds to the average annual productivity of biological production land | Type of land for biological production (kg/hm$^2$) | Equivalence coefficient | Ski tourism catering ecological footprint (hm$^2$) |
|---|---|---|---|---|---|---|---|
| Food products | 1.28 | 0.34 | 1.14 | 2744 | Cultivated land | 2.8 | 5.12 |
| pork | 1.28 | 0.07 | 1.14 | 74 | Grassland | 0.5 | 6.99 |
| Mutton | 1.28 | 0.01 | 1.14 | 33 | Grassland | 0.5 | 2.9 |
| Eggs | 1.28 | 0.03 | 1.14 | 400 | Grassland | 0.5 | 0.62 |
| Milk | 1.28 | 0.05 | 1.14 | 502 | Grassland | 0.5 | 0.75 |

Table 6. Ski Tourism Accommodation Facilities Ecological Footprint Account.

| Project | Nalati International Ski Resorts | Yilegedai Ski Resorts | Total |
|---|---|---|---|
| Number of beds in hotel rooms above level 4 | 0 | 0 | 0 |
| Number of beds in 3-star hotels and below | 5604 | 2473 | 8077 |
| Number of beds in inns, farm stays, and family hotels | 10497 | 325 | 10822 |
| Bed floor area /$hm^2$ | 24.15 | 41.97 | 66.12 |
| Type of land | Build-up area | Build-up area | |
| equivalence coefficient | 2.8 | 2.8 | |
| Accommodation ecological footprint /$hm^2$ | 67.62 | 117.52 | 185.14 |

Table 7. Ski Tourism accommodation energy consumption Ecological Footprint Account.

| Project | Nalati International Ski Resorts | Yilegedai Ski Resorts | Total |
|---|---|---|---|
| Number of beds | 16101 | 2798 | 18899 |
| Number of visitors (10,000 people) | 10300 | 2800 | 13100 |
| Room occupancy rate | 35% | 35% | |
| Energy consumption GJ/pcs | 0.04 | 0.04 | |
| Average calorific value GJ/$hm^2$ | 93 | 93 | 186 |
| equivalence coefficient | 1.1 | 1.1 | 2.2 |
| TEF of the energy consumption conversion site /$hm^2$ | 973.16 | 169.11 | 1142.27 |

consumption by tourists in the two major ski resorts is about 16.38 $hm^2$, and the ecological footprint number of ski tourism catering is 16.66 $hm^2$. The following table shows the calculation results of the ecological footprint of ski tourism catering.

### *Ecological Footprint of Accommodation in Ski Tourism*

The accommodation reception of tourists in Nalati Ski Resorts is mainly provided by Nalati Town. Data on the accommodation reception of Nalati Town, excluding the internal accommodation of Nalati Tourist Scenic Area, are used. And, the ecological footprint of the accommodation of Yilegedai Ski Resorts is calculated mainly based on the accommodation reception data of the located county, the daily bed occupancy rate of the two ski resorts is estimated at 35%, according to Ili government statistical data. The bedding equipment built-up area is estimated with reference to the evaluation standards of "Classification and Assessment of Tourist Hotel in China" (GB/T14308-2010). The area of a single bed in four-star and five-star hotels is estimated to be 20 $m^2$, and the area of a single bed in three-star hotels, inns et al are estimated to be 15 $m^2$. In addition, the energy consumption of the accommodation facilities is calculated according to the main used energy source [34], and the average calorific value is 93 GJ/$hm^2$ (www.engineeringtoolbox.com/fuels-higher-calorific-values-d_169.html). The ski tourism ecological footprint number of the accommodation facilities area and energy consumption of the accommodation facilities are 185.14 $hm^2$ and 1142.27 $hm^2$. And the ecological footprint number of the accommodation for ski tourism is 1327.41 $hm^2$. The following tables shows the ecological footprint of ski tourism accommodation facilities (Table 6) and the ecological footprint of ski tourism accommodation energy consumption (Table 7).

## Ecological Carrying Capacity of Ski Tourism

The proportion of forest land, grassland, construction land, water area, and fossil energy land are about 20.50%, 78.04%, 0.62%, 0.83%, and 0.00%. The proportion of cultivated land, forest land, grassland, construction land, and water area in Yilegedai Village is about 2.77%, 0.04%, 17.54%, 66.81%, and 12.86%, respectively. It is worth noting that the Nalati ski resorts barely occupies cultivated land, and Yilegedai ski resorts occupies no fossil energy land. The results indicate that the total ecological carrying capacity of both ski resorts is 1951.43$hm^2$, and the average ecological carrying capacity of the two ski resorts is about 0.152$hm^2$. The following table summarizes the ecological capacity results of the two ski resorts.

Table 8. Summary of ecological carrying capacity of ski tourism.

| Types of bio-productive land | Nalati Ski Resorts | Yilegedai Ski Resorts | Equivalence coefficient | Production coefficient | Ecological carrying capacity ($hm^2$) | Average ecological carrying capacity ($10^{-4}hm^2$) |
|---|---|---|---|---|---|---|
| Cultivated land | 0 | 0 | 2.8 | 2 | 0 | 0 |
| Woodland | 77.57 | 0.18 | 1.1 | 0.9 | 76.97 | 60.13 |
| Grassland | 295.30 | 77.18 | 0.5 | 0.2 | 37.25 | 29.10 |
| Construction land | 2.35 | 293.96 | 2.8 | 2.2 | 1825.27 | 1425.10 |
| Water area | 3.14 | 56.58 | 0.2 | 1 | 11.94 | 9.33 |
| Fossil energy land | 0 | 0 | 1.1 | 0 | 0 | 0 |
| The remaining area after deducting 12% of the area for ecological protection | 378.4 | 440 | | | 1951.43 | 1524.56 |
| Ecological carrying capacity of ski tourism | 121.41 | 1830.02 | | | | |
| Average ecological carrying capacity $10^{-4}hm^2$ | 94.85 | 1429.7085 | | | | |

## Ecological Surplus/Deficit Assessment

The per capita ecological footprint of the two major ski resorts is approximately 0.12 $hm^2$, and the average ecological carrying capacity is about 0.15 $hm^2$, indicating an ecological surplus of 0.13 $hm^2$. Specifically, the per capita ecological footprint of Nalati Ski Resorts is roughly 0.0095 $hm^2$, and the average ecological carrying capacity of ski tourism is about 0.089 $hm^2$, indicating an ecological deficit of 0.0006 $hm^2$. The per capita ecological footprint of Yilegedai Ski Resorts is about 0.14 $hm^2$, and the average ecological carrying capacity of ski tourism is about 0.029 $hm^2$, signifying an ecological surplus of 0.111 $hm^2$.

## Kernel Density Estimation

This study uses function of kernel density estimation in ArcGIS to analyze the kernel density of tourist attractions. That is designed to explore the agglomeration of the tourism industry and the ecological pressure of tourism in this region. The distribution pattern of attractions and the distribution pattern of ski resorts in the western part of Ili show a complementary feature. In areas with a high density of attractions, the number of ski areas is relatively low. Whereas in areas with lower density of attractions the number of ski resorts is larger. In the eastern part of Ili, the number of ski resorts and tourist attractions are both small. The results are shown in Fig. 1.

## Discussion

It is indicated that the ecological footprint of accommodation accounts for 87.65% of the tourism ecological footprint, comprises a significant portion of the ecological footprint in the two major ski resorts. That proves that the development strategy of the local tourist accommodation sector needs to be adapted. Among them, the ecological footprint of Nalati Ski Resorts is particularly prominent, given the abundance of accommodation facilities in Nalati Town, which resulted in large ecological pressure. Although Nalati Scenic Spot, which can attract more visitors to the area, is also located in Nalati town, the seasonal variations in ski tourism activities can affect the occupancy rate of accommodation facilities in the town. As a result, this leads to a high idle rate of accommodation facilities during the off-season and low ecological efficiency. Similarly, the abundance of accommodation facilities in Yilegedai can meet the needs of tourists during the tourist season. And the local attractions and the hotel occupancy rate are also strongly affected by the seasonality of ski resorts operations. Therefore, the oversupply of tourist accommodation services is the key problem to develop environmentally ski tourism. In addition, ecological footprint number of ski tourism transportation in the ski resorts is relatively small. When calculating transportation ecological footprint, this study only considered the distance between the two major ski resorts and their cities. Since these two ski resorts are the largest in Ili, they attract visitors from far beyond their counties, which means that tourists from more distant areas must have a larger transportation ecological footprint. On the other hand, although the two ski resorts are located near a national highway, with convenient transportation, the road network in the two counties is relatively sparse, resulting in a small ecological footprint of tourist transportation facilities. And the sparse transportation network forces tourists to choose hotels and guesthouses closer to the ski resorts, which accelerates the accumulation of local accommodation facilities and increases the ecological footprint of ski tourism accommodation.

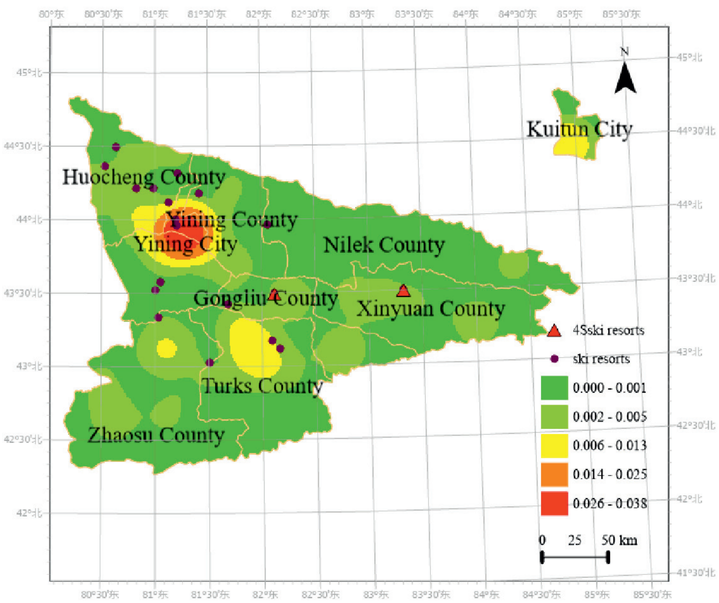


Fig. 1. Kernel density estimation results.

The ecological footprint of ski tourism and entertainment is mainly influenced by the area of ski resorts. And the ecological footprint of ski tourism catering is mainly influenced by the number of tourists, accounting for 11.19% and 1.08% respectively. Based on the ecological footprint accounts, it is indicated that the ecological footprint generated by the operation of ski resorts are much higher than that generated by tourist sightseeing and entertainment activities. The ecological footprint of maintaining the two ski resorts is greater than the ecological footprint of the tourist activities, and the ecological footprint of the two ski resorts are high. So the benefits of tourism operation cannot compensate for the ecological footprint. The distribution of attractions in Ili is concentrated with Yining City. Other cities have a lower density and more even distribution of attractions. In terms of the distribution of ski resorts, the spatial distribution of ski resorts in Ili is relatively scattered, fewer ski resorts in the east and more in the west. In general, the eastern region is suitable for the development of larger ski resorts.

And some policy can be considered: (1) Ili should develop tourism industry with considering about the local ecological pressure. And Ili should also protect the environment and develop the ski tourism industry in an eco-friendly way. (2) Combining the cultural characteristics of Xinjiang with ski tourism to create a skiing experience with unique character. In addition, other sports, cultural and creative industries should also be supported. And therefore, an integrated sports industry could be established in Ili. (3) Despite Ili has great natural resources for the development of ski tourism, it also faces challenges from domestic and foreign tourism markets. Ili should seize the opportunities offered by policies like China's Silk Road Economic Belt and 21$^{st}$-Century Maritime Silk Road Initiative, embrace government's encouragement and develop ski tourism.

## Conclusions

This study aims to explore an ecological accounting scheme for ski tourism, on evaluating the local ecological carrying capacity and ecological pressure, and to examine the sustainability of the regional skiing industry layout, based on a representative Tianshan ski tourist city. It is indicated that the ecological footprint of ski resorts is considerably larger than that of other tourism activities, which highlights the urgent need to manage ecological issues of ski resorts. The regional tourist attractions do not match ski tourism endowment. Main ski resorts, presents a state of ecological surplus, but Nalati, the largest ski resort in north slope region of Tianshan Mountain, is of ecological deficit. Ski tourism accommodations contribute to the largest proportion of the ecological footprint. There exist the over-abundance of local accommodation facilities, imperfection of the local transportation network, simplicity of the tourism industry structure and the seasonality of tourism activities. These have been increasing the ecological pressure of local ski tourism. Fundamentally, this study offers an industry ecological model consideration based on ski tourism sustainability assessment. Ili regional resource contributions to the great potentials for developing the ski tourism industry and creating large-scale and high-quality tourism products, especially in the east Ili. However, Ili ski tourism is currently facing significant ecological risks.

This study has provided a general overview of ecological carrying capacity and ecological footprint of Ski tourism. The evaluation model proposed in this study could be applied quantitatively the similar ski region, and provide a reference to evaluate the sustainability balancing the ski tourism industry with ecological protection. However, it will still be a long and ongoing process for the improvement of ecological carrying capacity and ecological footprint model. Further investigation and evidence of technology, regulation and others is still required to answer the question with further available data.

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## Conflict of Interest

The authors declare no conflict of interest.

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