Sustainability Assessment of Natural Capital Based on the 3D Ecological Footprint Model: A Case Study of the Shennongjia National Park Pilot

Yisong Wang 1, Jincheng Huang 1 and Shiming Fang 1,2,*

1 School of Public Administration, China University of Geosciences, Wuhan 430074, China; wys@cug.edu.cn (Y.W.); huangjincheng1995@outlook.com (J.H.)
2 Key Labs of Law Evaluation of Ministry of Land and Resources of China, Wuhan 430074, China
* Correspondence: fangsm@cug.edu.cn

Received: 20 November 2018; Accepted: 27 January 2019; Published: 13 February 2019

Abstract: The sustainability assessment of natural capital (SANC) is one of the key elements in the field of national park protection. Assessing the impact of socioeconomic development on the Shennongjia National Park Pilot (SNPP), a typical national park in China, would be extremely conducive to the sustainable management of its natural capital. To this end, a natural capital account system encompassing transportation, accommodation, food, and waste for both locals and tourists was developed. Throughout the period from 2007 to 2016, a SANC was conducted in SNPP based on the 3D ecological footprint (EF3D) model to measure stock consumption as well as flow occupancy. The main conclusions were as follows: First, the ecological footprint (EF) size of the SNPP increased yearly from 2007 to 2014, although it decreased in 2015, when the government started preparing for the SNPP. Second, rapid tourism-related developments brought about an increase in the EF of built-up land, and the increasing medicinal planting also enlarged the EF of arable land. Third, the cumulative EF of tourism was 2.82 times that of locals over the past decade. This gap has been expanding. Overall, the results show relatively steady sustainability in terms of natural capital in the SNPP. More precisely, the preceding stock consumption did not severely constrain the function of the current regeneration of flow capital, whereas tourism and planting have become potential threats to the sustainability of the natural capital.

Keywords: 3D ecological footprint; natural capital; national park; sustainability assessment; Shennongjia

1. Introduction

The World Commission on Protected Areas (WCPA) of the International Union for the Conservation of Nature (IUCN) has proposed and defined a global system for protected areas, within which the national park is the most common. The national park provides a foundation for environmentally and culturally compatible spiritual, scientific, educational, recreational, and visitor opportunities, while protecting the large-scale ecological processes, characteristic species, and ecosystems of the area [1]. To date, more than 8000 nature reserves and scenic spots have been established, but no national park system has yet been formed that strictly protects the natural ecological environment in coordination with China’s resource development and utilization. In order to explore a scientific and sustainable management mechanism for national parks, ten national park pilots have been proposed in China.

The establishment of national parks is an effective means to maintain stock capital and boost natural capital. However, in some cases, national parks are affected by human activities, such as the
destruction of animal habitats due to the results of recreational activities, such as garbage, local natural resource consumption by agricultural production [2], reduced national park space due to hotels and recreation trails [3], and soil erosion caused by traffic [4]. Unsustainable natural capital utilization is causing natural capital to be an increasingly limiting factor for human well-being in the Anthropocene era [5,6].

Natural capital, the most fundamental of the forms of capital, sets the ecological limits for our socioeconomic systems [7]. Environment and development economics theory states that maintaining natural capital is the corner-stone of sustainable development [8]. However, the significance of natural capital used to be overlooked when making decisions. Consequently, the sustainability assessment of natural capital (SANC) provides insights into designing environmental policy and sustainable development planning. At present, the SANC does not have a mature evaluation system that can directly interface with economic development. Hence, studies on natural capital mainly adopt ecological footprint (EF) [9], ecosystem service valuation [10], energy theory [11], net primary productivity [12], life cycle assessment [13], etc. Currently, the SANC generally relies on various EF methods [14–17]. These methods can clearly quantify human occupation and the supply of natural capital, which are more operative and less subjective for the SANC.

The EF model is a mature approach for quantitatively measuring the effect of human occupation on natural capital, and has been applied at various scales, including national parks and other types of protected areas [18–20], and has been combined with 3S technology [13], the coefficient matrix method [21], time series analysis, and other technical methods [22–24]. The 3D ecological footprint (EF3D) model overcomes the shortcomings of the traditional EF model, which exclusively focuses on flow capital and overlooks the significance of stock capital in sustainable development. Hitherto, the EF3D model has been applied in Chinese multi-scale studies relating to countries, metropolitan areas, river basins, etc. [25–30], but it remains to be used in the context of national parks.

In this article, we construct an applicable SANC account system for Shennongjia National Park Pilot (SNPP), in China’s national park system, and apply the EF3D model to evaluate the impact of locals’ daily lives and tourists’ activities in the national park on the local natural capital, which can provide reference for other national parks.

2. Study Area

The Shennongjia National Park Pilot (SNPP) (in Figure 1) (109°56′–110°36′ E, 31°17′–31°36′N) is located in Shennongjia Forest Region, Hubei Province, China, and is one of ten pilots of the first batch of national parks established in 2016. The total area is 1170 km², and it belongs to the north subtropical monsoon climate and humid region. SNPP is situated on the eastern edge of the second step of the Chinese terrain, belonging to the middle and high mountains in the east of the Daba Mountain Range. The overall terrain is high in the southwest and low in the northeast. There are four distinct seasons throughout the year and the annual average temperature is 12 °C [31].

The vast majority of the park is situated in Dajiuhu Town, Xiagu Township and Muyu Town, which have up to 91.1% of the forest coverage rate. As an outstanding representative of the mountain ecosystem at this global latitude, the SNPP will be subject to long-term maintenance in terms of biodiversity habitat, ecosystem type, and biological evolution. More specifically, ancient rare and endemic species abound, such as the golden snub-nosed monkey. The evergreen deciduous broad-leaved mixed forest is well preserved for the northern hemisphere. The complete vegetation band spectrum lies in the northern subtropical mountain range. The extremely rare subalpine peat moss wetland, ancient geological relics and flora and fauna fossils also exist, as well as rare mountain culture circles in Asia [32].
3. Materials and Methods

3.1. Overall Approach

We investigated the sustainability of natural capital in SNPP in three major steps. First, we established a SANC account system comprising transportation, accommodation, food, and waste sub-accounts for both locals and tourists in national park. Second, we measured the 3D ecological footprint based on the EF$_{3D}$ model in SNPP from 2007 to 2016 in Supplementary Materials. Third, we adopted a series of indicators to evaluate the sustainability of the natural capital. The framework of the study is illustrated in Figure 2.

3.2. Account System for the Sustainability Assessment of Natural Capital

In this study, the natural capital categories were built-up land, forest land, arable land, water, and grassland. In light of previous research, the SANC account system consisted of transportation, accommodation, food, and waste sub-accounts [33–36]. Elaborated in Table 1, the four sub-accounts cover 10 assessment items corresponding to 28 elements. All these items were selected under consideration of the local situation and data availability.

The evaluating target in the transportation sub-account was built-up land. The road area refers to the sum of the products of the width and length of different grade roads. The different grade road lengths in specific years were acquired from the Shennongjia Statistical Yearbook (2007 to 2016) [37]. Widths were consistently supposed to be the median value of the width, the ranges of which come from a national standard named the Quota Indexes of Urban Planning [38]. Parking lot area refers to the product of the parking area per vehicle and the number of vehicles including civil cars, lorries.
and passenger cars. The numbers of these three kinds of vehicles were obtained from the Shennongjia Statistical Yearbook (2007 to 2016) [37], and the parking area per vehicle was obtained from the Code for Urban Parking Planning (GB/T51149-2016) [39]. The parking area for motor vehicles on the ground was set as 25 to 30 m\(^2\) according to this standard, thus we set the median value of 27.5 m\(^2\) as the parking area per vehicle. The accommodation area of tourists and the living area of residents were counted in the accommodation sub-account. The total area of built-up land in the accommodation industry was the product of the area per bed and the number of existing beds, and the living area of locals was the product of living area per capita and the total population in the SNPP. The area per bed in star hotels was based on the research by Gössling et al [40], and the number of existing beds in hotels and the living area per capita were obtained from the Shennongjia Statistical Yearbook (2007 to 2016) [37].

**Table 1.** The sustainability assessment of natural capital (SANC) account system.

<table>
<thead>
<tr>
<th>Sub-Accounts</th>
<th>Assessment Items</th>
<th>Assessment Contents</th>
<th>National Capital Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation</td>
<td>Parking lot area</td>
<td>Civil cars</td>
<td>Built-up land</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lorries</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Passenger cars</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Road use area</td>
<td>State roads</td>
<td>Built-up land</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Provincial roads</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>County roads</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Township roads</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Village roads</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Special highways</td>
<td></td>
</tr>
<tr>
<td>Accommodation</td>
<td>Accommodation area</td>
<td>Hostel areas in national parks</td>
<td>Built-up land</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Locals total living area</td>
<td></td>
</tr>
<tr>
<td>Waste</td>
<td>Sewage discharge</td>
<td>Sewage</td>
<td>Water</td>
</tr>
<tr>
<td></td>
<td>Exhaust emission</td>
<td>CO(_2)</td>
<td>Forest land</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SO(_2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soot</td>
<td></td>
</tr>
<tr>
<td>Food</td>
<td>Agricultural product consumption</td>
<td>Grains</td>
<td>Arable land</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oil</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vegetables</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medicinal materials</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Toobaccos</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Meat products</td>
<td>Cattle</td>
<td>Grassland</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sheep</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Forest products</td>
<td>Raw lacquers</td>
<td>Forest land</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Walnuts</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chestnuts</td>
<td></td>
</tr>
<tr>
<td>Aquatic products</td>
<td>Aquatic products</td>
<td>Aquatic products</td>
<td>Water</td>
</tr>
<tr>
<td>Meat products</td>
<td>Pigs</td>
<td>Poultry</td>
<td>Built-up land</td>
</tr>
</tbody>
</table>

Part of the EF of water was measured in the waste sub-account based on calculating the ecological productive area occupied by treating sewage; 1 ha of water can treat 365 t of sewage according to previous research [41]. Part of the EF of forest land was also measured in the waste sub-account based on calculating the ecologically productive area occupied by CO\(_2\), soot and SO\(_2\) emissions [42,43]. CO\(_2\) emissions was calculated as the production of the carbon emission coefficient of CO\(_2\) and the annual standard coal consumption, and we assumed that the CO\(_2\) emissions in SNPP were only absorbed by forest land. The annual standard coal consumption and soot and SO\(_2\) emissions were obtained from the Shennongjia Statistical Yearbook (2007 to 2016) [37]. The recommended value of the carbon emission coefficient of CO\(_2\) was 0.67 t\(_{ce}\)/t\(_{ce}\), obtained from the Energy Research Institute of the National Development and Reform Commission [44]. The annual rate of CO\(_2\) sequestration per hectare of
The world average forest land is 2.70 tC\,hara\,yr\,^{-1} [45]. The forest capacity for soot adsorption and SO\(_2\) adsorption is 2.1655 t/ha and 152.05 kg/ha [46], respectively.

The food sub-account involves all kinds of natural capital. We calculated productive EF rather than consumptive EF, therefore all kinds of resource consumption are presented by local production data [37, 47, 48]. The yields of agricultural products in arable land are formed by grains, oil, vegetables, and tobaccos. In contrast to cattle and sheep that live in the open most of the time, pigs as well as poultry are usually fed in fixed shelters classified as built-up land rather than arable land or grassland [49].

To compare different categories of natural capital, the yield factors and equivalence factors must be utilized under the account system. The yield factors refer to the index proposed by Liu et al. [50]. The equivalence factors were provided by the Global Footprint Network [51]. In the calculation of the ecological capacity, 12% of the ecological area should be deducted for biodiversity conservation according to the requirements of the World Commission on Environment and Development.

### 3.3. 3D Ecological Footprint Model

On the basis of the traditional EF model, Niccolucci et al. tried to construct a three-dimensional EF model by introducing EF depth and EF size to distinguish stock capital and flow capital [52–54]. Fang et al. improved the model to solve the problem that the ecological deficit (ED) and ecological surplus (ES) of different land types are irreplaceable [55–59]. This approach was used in this study.

EF depth represents the degree of human consumption of stock capital and has a time attribute [55]. EF size represents the degree of human occupation of flow capital and has a spatial attribute [55]. As a tool reflecting the stock capital decline, the EF\(_{3D}\) model can be used to judge the sustainability of providing resources, products and waste absorption services, based on three criteria presented by Daly et al. [56]. Therefore, the following equation was established:

\[
EF_{3D} = EF_d \times EF_s
\]

where \(EF_{3D}\) refers to the three-dimensional EF; \(EF_d\) refers to EF depth; and \(EF_s\) refers to the EF size. Niccolucci found that EF has traditionally been presented as an area-based indicator and visualized as the size of the foot [53]. In Figure 3, EF is shown as a circle in which the blue area is ecological capacity (EC), while the total area enclosed by the dark line is EF. The ring (white area) is ED. The EF\(_{3D}\) model regards EF as a cylinder implemented by EF size (bottom) and EF depth (column height) [53].

![Figure 3. Development of the ecological footprint models from 2D to 3D [54].](image)

In theory, the EF size in the EF\(_{3D}\) model is still consistent with that in the EF\(_{2D}\) model, despite its characteristic focus on volume rather than area. The unit of EF is global hectare (gha), 1 gha refers to the ecological productivity and waste absorption capacity equivalent to the global average of 1 ha of land [55].
EF size implies the actual occupied area of ecologically productive land within the limits of regional ecological capacity [56]. The indicator characterizes the level of flow occupation by human-beings. The implication emphasizes the spatial scarcity of land resources. The formula for calculating EF size is:

$$EF_{s,i} = \sum_{i=1}^{n} \min \{ EF_i, EC_i \}$$

where $EF_{s,i}$ refers to the EF size in certain natural capital categories; $i$ refers to a certain natural capital category; $n$ refers to the total number of natural capital categories; $EF_i$ refers to the EF in a certain natural capital category; and $EC_i$ refers to the ecological capacity in a certain natural capital category. The range of EF size is from 0 to EC, indicating that the upper limit for the ecosystem for which supply flow capital is being measured is EC.

EF depth represents the occupation multiple of the regional ecological productive land area theoretically required to maintain the current level of resource consumption, which characterizes the degree to which humans consume the natural capital in one year [56]. The formula for calculating EF depth is:

$$EF_{d,i} = 1 + \frac{\sum_{i=1}^{n} \max \{ ED_i, 0 \}}{\sum_{i=1}^{n} EC_i} = 1 + \frac{\sum_{i=1}^{n} \max \{ EF_i - EC_i, 0 \}}{\sum_{i=1}^{n} EC_i}$$

where $EF_{d,i}$ refers to the EF size in a certain natural capital category.

ED refers to the ecological deficit, which reflects the relative difference between EF and EC, and which is the concept corresponding to ecological surplus, reflecting the human resource demand beyond EC [56].

When the EF depth is equal to 1, it represents the natural depth. At this time, people only need to occupy the flow capital to meet their own needs, and the stock capital is not consumed.

When the EF depth is greater than or equal to 1, the greater the value, the greater the human consumption of the stock capital, and the weaker the sustainability of the natural capital utilization.

The EF3D model adds a time scale and summarizes the EF dynamics of a national park on the basis of the traditional EF model [57]. Therefore, the EF3D model can comprehensively characterize the actual state of natural capital utilization.

### 3.4. Indicators for the Sustainability Assessment of Natural Capital

#### 3.4.1. Theoretical Ecological Footprint Size

Hypothetically, the continuous stock reduction supplied by the ecosystem will potentially restrict flow generation in the future in an enclosed region. As a result, the theoretical EF size is created to deduct the ecological deficit of this year when calculating the flow capital for the next year [57]. The formula for the theoretical EF size is:

$$EF_{s,th}^y = EF_s^y - \left( EF_{d}^{y-1} - 1 \right) EF_s^{y-1}$$

where $EF_{s,th}^y$ refers to the theoretical EF size for $y$ years; $EF_s^y$ refers to EF size for $y$ years; $EF_{d}^{y-1}$ refers to the EF depth for $y-1$ years; and $EC_s^{y-1}$ refers to the ecological capacity for $y-1$ years.

$$EF_s^y \leq ED_{th}^{y-1} \quad EF_{s,th}^y = 0$$

where $ED_{th}^{y-1}$ refers to the theoretical ecological deficit for $y-1$ years.

The equation indicates that excessive stock consumption could critically hinder the renewable capacity of flow capital. It also further reflects the qualitative difference between ED and ES. The essence of ES is a kind of residual EC, which is the real land area, and which cannot be accumulated year by year. ED represents the virtual land area overdrawn by human beings, which is similar to an ecological debt and can be accumulated year by year [57].
3.4.2. Cumulative Ecological Footprint Size

In line with fairness and sustainability, which are principles of sustainable development, a fair relationship between “inter-generational” and “intra-generational” concerns are supposed to consider the allocation of the natural capital of national parks [57]. As such, it is indispensable to take the relationship between “degree” or “capacity” into account in the development and utilization of resources and the environment by accumulative EF size [55]. The formula for the accumulative EF size is:

\[ EF_{s,c} = \sum_{z=1}^{m} EF_z + \sum_{z=m+1}^{y} EC_z \times (EF_m < EC_m \times EF_{m+1} \geq EC_{m+1}) \]  

where \( EF_{s,c} \) refers to the cumulative EF size; \( m \) refers to the number of years of ecological surplus; \( y \) refers to the total number of years; \( EF_z \) refers to the EF of \( z \) years; and \( EC_z \) refers to the ecological capacity of \( z \) years.

3.4.3. Appropriation Rate of Flow Capital

When flow capital is partially occupied, the appropriation rate of flow capital is used to characterize the actual occupancy degree of flow capital in research [58].

\[ A_{fc} = \frac{EF_s}{EC} \times 100\% \times (EF < EC) \]  

where \( A_{fc} \) refers to the appropriation rate of flow capital; \( EF_s \) refers to EF size; and \( EC \) refers to ecological capacity.

3.4.4. Use Ratio of Stocks to Flows

When flow capital is completely occupied and stock capital tends to be consumed, the use ratio of stocks to flows characterizes the number relationship between natural capital stock consumption and flow occupation [58].

\[ U_{fs} = \frac{ED}{EF_s} = \frac{EF - EF_s}{EF_s} = EF_d - 1(\text{EF} > \text{EC}) \]  

where \( U_{fs} \) refers to the use ratio of stocks to flows; and \( ED \) refers to the ecological deficit.

4. Results

4.1. Ecological Footprint

In general, the total EF rose sharply in 2010, and then continued to improve, visibly decreased in 2015, and eventually went up to 32,962.15 gha in 2016. Figure 4 delineates the variant components of EF in SNPP from 2007 to 2016. The forest land EF and arable land EF are the main reasons for the integral dynamic. The arable land and built-up land both showed gradual upward tendencies. The forest land EF first increased, then remained at a corresponding stable level, before plunging in 2015. Meanwhile, the changes in the EF of water and grassland were unambiguous.

The EF contribution rates from the five categories of nature capital had striking disparities in the period 2007 to 2016. Briefly speaking, forest land accounted for the greatest contribution to EF, followed by arable land, with built-up land ranking third, water fourth, and grassland fifth.

The contribution rates of built-up land and arable land increased, while the contribution rates of forest land, water, and grassland declined. The contribution rates of different natural capital categories showed a large fluctuation in SNPP. The dominant factors were forest land EF and arable land EF.
Figure 4. Five components of the ecological footprint in SNPP in the period 2007 to 2016.

4.2. 3D Ecological Footprint

4.2.1. Ecological Footprint Depth

The EF depth of the SNPP (red line) shown in Figure 5 increased from 1.0003 to 1.0098, close to the natural depth, indicating that the stock capital was well-preserved and the flow capital was relatively stable during the period. The EF depth of the arable land, forest land, and grassland remained at 1 over the past decade, indicating that these kinds of flow capital were able to meet local demand for resource consumption and waste absorption. The reason that the EF depth of the SNPP was over 1 was mainly the EF depth of water (blue rectangle) before 2008, and the EF depth of built-up land (grey rectangle) after 2011. Specifically, the EF depth of water decreased at an annual average reduction rate of 7.87% until it became 1 in 2009, revealing that the stock consumption of this resource had ceased, and the ecological deficit was effectively controlled in SNPP. In contrast, the EF depth of built-up land increased constantly at an average annual growth rate of 3.77%, except in 2009 and 2010. It is possible to note that the flow occupation of built-up land is gradually becoming unable to meet local development demands.

Figure 5. Trend of the depth of the ecological footprint in SNPP in the period 2007 to 2016.
4.2.2. Ecological Footprint Size

The EF size of forest land, arable land and built-up land accounted for over 99% of the total EF size in SNPP from 2007 to 2016. Figure 6 shows that the EF size of forest land initially grew slowly, then increased rapidly from 2009 to 2014, declining sharply after 2015. This is due to the remarkable effectiveness of control measures for emissions of CO$_2$ and SO$_2$ since the government started preparing for SNPP.

The EF size of arable land increased by 51.74% during the decade. The EF size of built-up land did not change obviously, as the EF size was assigned to the EC, that is, when the EF exceeds the EC of built-up land it is basically invariant. Owing to the continuous reduction of gross sewage discharge in recent years, the EF size of water was cut back, with an average reduction rate of 7.87%. The EF size of grassland showed almost no change, indicating that the flow capital remained relatively stable under the impact of local meat consumption.

The flow occupation in the accommodation sub-account increased, which was driven by the number of incoming tourists in one year increasing significantly. Additionally, the flow occupation in the transportation sub-account increased as a result of the repair of township and county roads. Eventually, they led to the ecological deficit of built-up land.

Figure 7 shows the theoretical EF size during the period. The ecological deficit accumulated year by year, viewed as an unsustainable environmental impact. The gap between theoretical EF size and the actual EF depth is actually the ecological deficit, which is not significant. The ecological deficit of the previous year did not have a great impact on the ecological capacity of the current year, indicating that preceding stock consumption did not seriously restrict the current capacity of flow regeneration. However, it should be noted that the theoretical EF size of arable land declined. The negative influence of cumulative ecological deficit has been increasing in recent years. The ecological capacity of arable land will continue to decrease, which can generate a potential threat to the stock capital.
4.2.3. Trend of the 3D Ecological Footprint

As shown in Figure 8, the SNPP was considered to be a cylinder with a gradually changing volume. The bottom of the cylinder increased continuously from 2011 to 2015. Synchronously, the column height generally showed an upward trend, resulting in an increase in the total volume, indicating that the stock consumption and flow occupation were both increasing. The height continued to increase in 2016, but the bottom decreased, resulting in a decrease in total volume. It shows that the 3D ecological footprint had begun to decrease, and the natural capital supply pressure had been effectively alleviated after the establishment of SNPP.

Figure 8. Graphic comparison of EF3D in SNPP in the period 2007 to 2016.
4.3. Stocks and Flows of Natural Capital

In Table 2, it can be seen that the appropriation rate of flow capital of SNPP had gradually increased before 2014, then begun to decline. During the study period, the per year appropriation rate of flow capital was no more than 30%, along with an annual average growth rate of only 3.59%, indicating that the flow occupation nevertheless increased, but not by much. The appropriation rate of flow capital of forest land and grassland was small. The consumption rate of water stocks slowed down in the first two years and stopped in 2009. In the following year, the appropriation rate of the flow capital of water generally showed a decreasing trend, indicating that the establishment of SNPP effectively controlled the flow occupancy of this natural capital. In contrast, the appropriation rate of the flow capital of arable land tended to increase on the whole, and the growth rate in 2016 increased significantly. The use ratio of stocks to flows of built-up land was larger and larger, and reached 0.45 in 2016, indicating that the threat of stock consumption was visibly expanding.

<table>
<thead>
<tr>
<th>Year</th>
<th>Built-Up Land</th>
<th>Forest Land</th>
<th>Arable Land</th>
<th>Water</th>
<th>Grassland</th>
<th>SNPP</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>0.00</td>
<td>12.01%</td>
<td>52.58%</td>
<td>0.41</td>
<td>0.74%</td>
<td>17.64%</td>
</tr>
<tr>
<td>2008</td>
<td>0.03</td>
<td>12.33%</td>
<td>52.79%</td>
<td>0.05</td>
<td>0.64%</td>
<td>17.97%</td>
</tr>
<tr>
<td>2009</td>
<td>98.96%</td>
<td>12.94%</td>
<td>55.50%</td>
<td>78.53%</td>
<td>0.62%</td>
<td>18.77%</td>
</tr>
<tr>
<td>2010</td>
<td>97.28%</td>
<td>15.90%</td>
<td>57.84%</td>
<td>99.87%</td>
<td>0.62%</td>
<td>21.62%</td>
</tr>
<tr>
<td>2011</td>
<td>0.12</td>
<td>18.68%</td>
<td>58.42%</td>
<td>64.99%</td>
<td>0.59%</td>
<td>24.18%</td>
</tr>
<tr>
<td>2012</td>
<td>0.09</td>
<td>19.98%</td>
<td>60.22%</td>
<td>65.47%</td>
<td>0.54%</td>
<td>25.58%</td>
</tr>
<tr>
<td>2013</td>
<td>0.11</td>
<td>21.15%</td>
<td>60.86%</td>
<td>74.03%</td>
<td>0.65%</td>
<td>26.70%</td>
</tr>
<tr>
<td>2014</td>
<td>0.17</td>
<td>21.36%</td>
<td>68.17%</td>
<td>64.80%</td>
<td>0.72%</td>
<td>27.55%</td>
</tr>
<tr>
<td>2015</td>
<td>0.24</td>
<td>17.64%</td>
<td>64.99%</td>
<td>72.25%</td>
<td>0.79%</td>
<td>24.01%</td>
</tr>
<tr>
<td>2016</td>
<td>0.45</td>
<td>14.97%</td>
<td>82.15%</td>
<td>62.28%</td>
<td>1.03%</td>
<td>23.33%</td>
</tr>
</tbody>
</table>

*Values with “%” represent the appropriation rate of flow capital and other values represent the use ratio of stocks to flows.

4.4. Ecological Footprint Size for Locals and Tourists

Correlating with the process of local socioeconomic development, the tourism industry had a notable impact in SNPP. To assess the EF size of tourists in SNPP, we applied the tourist estimation method [12]. This approach compares the visitors’ EF with locals’ EF by using the concept of “annual equivalent residents”.

As shown in Figure 9, the cumulative EF of the tourists was 2.82 times that of the locals over the entire period. The tourists’ EF size surpassed the locals’ EF size in 2008, and the contribution of the tourists’ EF increased from 43.87% in 2007 to 90.52% in 2016. This is because the number of visitors increased twelve-fold during this decade. The increasing visitors generated a large EF for almost every item, especially food consumption and accommodation. Fortunately, the per capita EF size is declining at an average annual rate of 14.58%, which effectively slows the growth of the total EF size in SNPP. However, the linear growth in the EF of tourists should not be ignored, as tourism expansion is still the biggest threat to the sustainability of natural capital in SNPP.
would ensure that ecosystem security is compromised by recreational activities in nature reserves.

Sustainability 2019, 11, 956

...regular land use policies, such as burning for electricity, shutting down a sandstone factory, and stopping exploration mining, which has significantly reduced the emissions of SO2 and CO2. Besides, the declining gross sewage discharge also reduced the water EF in SNPP.

5. Discussion

5.1. Dynamics of the Ecological Footprint

Overall, the flow occupation and stock consumption was relatively reasonable in SNPP from 2007 to 2016. However, it is non-negligible that the stock consumption of built-up land and the flow occupancy of arable land are constantly accelerating. These results of the exploration in Shennongjia is similar to the findings by Ma from about the same time [60].

There are three negative dynamics for this exploration: First, the contribution rate of the accumulative EF size of arable land has reached 60.66%, because agriculture is still fundamental for locals in the national park. Second, the local government has been developing the farming of specific medicinal herbs, resulting in the output of medicinal herbs having quadrupled over the past decade. Third, the interest in natural capital has risen enormously due to the expansion of tourism development in recent years. To date, some scholars have found that visitors' EF exceeded that of locals in tourism destinations, ranging from many famous tourist cities, to scenic spots and forest parks in China [61–63]. Furthermore, the General Plan for Land Use in Shennongjia Forest Region 2006–2020 indicates that the built-up land area will be moderately expanded for tourism in the future [64].

Fortunately, the forest land, which has excellent resource endowments, was only occupied by a small amount of flow capital in SNPP. This circumstance was principally due to the creation of artificial afforestation and closure of afforestation policies, as well as the low population density. Moreover, the flow occupation of forest land has plummeted since the government started preparing for SNPP in 2015 by launching a series of protection policies such as burning for electricity, shutting down a sandstone factory, and stopping exploration mining, which has significantly reduced the emissions of CO2, soot and SO2. Besides, the declining gross sewage discharge also reduced the water EF in SNPP.

5.2. Suggestions for SNPP

As we all know, the main purpose of establishing a national park is to protect biodiversity and significant ecosystems as well as to maximize the recreational value of natural capital, although the former is more essential. However, excessive recreational activities can adversely affect the natural environment, causing for example landscape degradation, habitat destruction, disturbances to wild species, and changes in indigenous environment perceptions [65]. A sustainable tourism mode would ensure that ecosystem security is to compromised by recreational activities in nature reserves.
Additionally, reserving sufficient development space for locals is one of the essential tasks of national park management. To achieve the UN Sustainable Development Goals [66], the local government should lay down further related policy measures. First, adapting the scale of tourism to the reception capacity is necessary to meet future challenges. Second, large-scale built-up land constructions, such as accommodation industries and shopping malls, should maintain their current size or move outside the national park boundary. Third, providing locals with reasonable compensation could continue to promote an ecological immigration policy. Fourth, it is feasible to guide tourists to regulate their recreational behavior, by promoting ecological education to prevent the rapid development of tourism from becoming unsustainable. Moreover, the development of medicinal planting must take local conditions into account. Different planting patterns should be adopted for different medicinal types to promote the sustainable development of local natural capital.

5.3. Limitations and Future Work

While the EF size and the depth of the EF\textsubscript{3D} model are conducive to the representation of natural capital utilization, it has a limitation in terms of representing natural capital stocks [59]. Hence, we estimated the sustainability of the natural capital in SNPP based on natural capital utilization rather than the explicit value of the natural capital. The long time series analysis of this study makes it easier to discover the variation tendency of the sustainability of natural capital than using a static evaluation. However, the comprehensiveness and integrality of the long-term dataset is difficult to obtain, so we eliminated the indicators for which we were unable to collect complete data for the period covered by the SANC account system. Hence, in the future we will investigate more exogenous factors like natural disasters and climate change to enrich the SANC account system and conduct comparative studies in different national parks.

6. Conclusions

This article presents a SANC account system suitable for Chinese national parks. The EF as well as EF depth and size were measured based on the EF\textsubscript{3D} model in SNPP from 2007 to 2016. The dynamics of five categories of natural capital in terms of stock consumption and flow occupation were analyzed, and the following findings were obtained:

(1) The total EF in SNPP reached 31,627.02 gha in 2016. In addition to the increase in the arable land EF and forest land EF, the dynamics of the other natural capital were small over the ten years. In general, the current natural capital in SNPP is relatively sufficient and the stocks do not seriously restrict the future regeneration function of flow capital.

(2) The stock consumption in SNPP represented a tiny fraction, and the EF depth was between 1.0003 and 1.0098. This was mainly ascribed to the increasing demand for tourism development resulting in built-up land. The EF size increased year by year from 2007 to 2014, and decreased in 2015, because energy consumption and waste emissions plunged since the government started preparing for SNPP. However, the EF of arable land increased throughout due to the rapid growth in medicinal planting.

(3) The contribution rate of tourists’ EF increased 46.41% to the total local EF from 2007 to 2016. Compared with locals’ EF, tourists’ EF increased 0.78 times in 2007 to 8.99 times in 2016. The accumulative EF of tourists was 2.82 times that of locals over the past decade. The results show that tourism has become the largest potential threat to the sustainability of natural capital in SNPP. Therefore, the scale of tourism ought to be reasonably controlled and a balance should be maintained between medicinal planting and ecosystem protection for SNPP in the future.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/11/4/956/s1, Table S1: The SANC account system in SNPP in the period 2007–2016. Table S2: Ecological footprint in SNPP in the period 2007 to 2016. Table S3: Equivalence factors and yield factors.
Author Contributions: Conceptualization, S.F.; Data curation, Y.W.; Formal analysis, Y.W.; Investigation, Y.W.; Methodology, Y.W. and J.H.; Project administration, S.F.; Supervision, J.H.; Validation, J.H.; Visualization, J.H.; Writing-original draft, Y.W.; Writing-review and editing, S.F.

Funding: This work was supported by National Natural Science Foundation of China (41201574 and 41671518), the Key Project from the National Social Science Foundation (18ZDA053), and Human and Social Science Foundation of Ministry of Education (16YJAZH018) in China, as well as the Fundamental Research Funds for the Central Universities, China University of Geosciences (Wuhan) to Shougeng Hu.

Acknowledgments: The authors wish to acknowledge MDPI English Editors Linnea Andersson and Jack Sissons for correcting manuscript in grammar and syntax.

Conflicts of Interest: The authors declare no conflict of interest.

References
8. Hanley, N.; Dupuy, L.P.; Mclaughlin, E. Genuine savings and sustainability. J. Econ. Surv. 2015, 29, 779–806. [CrossRef]
14. Patterson, T.M.; Niccolucci, V.; Bastianoni, S. Beyond “more is better”: Ecological footprint accounting for tourism and consumption in Vai di Merse, Italy. Ecol. Econ. 2007, 62, 747–756. [CrossRef]
15. Monfreda, C.; Wackernagel, M.; Deumling, D. Establishing national natural capital accounts based on detailed ecological footprint and biological capacity assessments. Land Use Policy 2004, 21, 231–246. [CrossRef]


52. Niccolucci, V.; Galli, A.; Reed, A.; Neri, E.; Wackernagel, M.; Bastianoni, S. Towards a 3d national ecological footprint geography. Ecol. Model. 2011, 222, 2939–2944. [CrossRef]


60. Ma, Y.; Li, L.X.; Ren, J. Coordination development research among the tourism Economy-Traffic Condition-Ecological environment in Shennongjia Forest District. Econ. Geogr. 2017, 37, 215–220. [CrossRef]


© 2019 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).