Spatio-temporal variations of conservation hotspots based on ecosystem services in Xishuangbanna, Southwest China

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Abstract

Integrating biodiversity and ecosystem services (BES) has been viewed as an appropriate approach to identifying conservation priorities. Taking Xishuangbanna tropical region in Southwest China, different BESs (habitat quality [used as a proxy for biodiversity], carbon storage, and water yield) were quantified using the InVEST model and conservation hotspots from 1976, 1990, and 2010 were identified by overlapping and ranking the service layers. Results showed that BESs areas were unevenly distributed. High habitat quality and carbon storage areas located in the eastern part of the region were mainly occupied by broad-leaved forest, while high water yield areas were covered by grassland and tropical forests. Recognized hotspots were primarily composed of the broad-leaved forest and shrub grassland. However, these habitat types declined by nearly 50% from 1.25×10^5 ha to 0.63×10^5 ha and became more fragmented during the study period. We also found that the sub-watersheds which decreased in BES had fewer hotspots distributed and suffered greater landscape fragmentation. Our study further explored the impacts of land-use conversion on BES, and illustrated the necessity and feasibility of BESs in identifying potential conservation areas.

1. Introduction

Land conversion from natural forest to agricultural land or built-up land has been reported worldwide in recent decades, putting continuous pressures on local ecosystems and landscapes, especially biodiversity and habitat quality in some tropical regions [1–3]. Previous studies have only focused on biodiversity when planning conservation strategies [4,5]. However, systematic conservation planning should take into account landscape pattern, ecological vulnerability and anthropogenic threat [6]. As biodiversity is a determinant of ecosystem process and plays a key role in many ecosystem services [7,8], both biodiversity and ecosystem services (BES) should be modeled to identify hotspots through comparing their spatial patterns [9]. Ecosystem services, bridging natural ecology and the needs of human society, are the rationale for practical applications for environmental sustainability and conservation plans [10–12]. Some strategies have been geared toward combining biodiversity with ecosystems services...
in terms of comprehensive application in planning sustainable conservation interventions [13,14]. For conservation, the term “hotspot” was originally used for regions only with high species richness for biodiversity conservation [5]. In our study, “hotspot” means sites or areas which have high BES values.

Land-use management and planning (reforestation, plantation, agricultural practices, and human activities) can cause variations in the spatial provision of ecosystem services [8,15]. Land-use change (LUC) affects the process of local material circulation and energy flow while changing landscape patterns [16]. Decisions about land-use usually aim to maximize a single output such as wood or agricultural production, but such decisions often generate an attendant decline of other ecosystem services [17]. Therefore, it is vital to find out the relationship between LUC and biodiversity and ecosystem services change (BESC) at a specific scale, and reduce the threats to biodiversity as well as improve regional sustainable development.

Spatially explicit values of ecosystem services that might reflect land-use and management decisions are still not enough [17]. The InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) model provides practical tools to visualize the ecosystem services. As a spatially explicit integrated modeling tool, it is a suite of GIS models and algorithms that converts changes in land-use patterns into changes in ecosystem services [18]. There have been many studies that have used the InVEST model to explicitly elucidate different ecosystem services [8,19], and to analyze as well as forecast ecosystem service dynamics under stakeholder-defined scenarios of land use [3,20]. In China, this model has been applied to the Three Rivers Source Areas, Qinghai province, Poyang Lake and some other key ecological regions [21–23], except Southwest China which is abundant in biodiversity and ecosystem services.

The composition and configuration of different ecosystems within a changing landscape are so influential to the alteration of biochemical and biophysical conditions, that the provision of ecosystem service from these conservation hotspots may be affected [24,25]. In this unique tropical region in China, conservation priorities are rarely related to the management of ecosystem services [26], and the interaction between landscape patterns and ecosystem services is still unclear. For the sub-watershed scale, explorations of the relationship between landscape pattern and ecosystem service has practical implications. This helps us understand the interaction of LUC and BESC as well as makes understanding ecosystem service variations detected in the local area more intuitive.

Xishuangbanna prefecture, as a typical rainforest area in Southwest China, has been affected by dramatic LUC in recent years and is facing enormous threats from human activities [27]. Economic growth principally related to local road construction and urban sprawl has resulted in the destruction of natural forests. LUC in Xishuangbanna is characterized by the destruction of the natural forest, the extension of artificial forests such as rubber and tea plantations, and construction areas [28,29]. Furthermore, deforestation here has caused ecological problems as well as the eco-environmental imbalance influenced by LUC [30]. Obviously, its residential or construction areas continue increasing at the expense of natural forestland [31–33]. Many local species are threatened by the loss of habitat, such as Asian elephant (Elephas maximus), whose endangered status has been blamed on the natural forest shrinking due to farmland cultivation, infrastructure construction and city expansion [34,35]. So, it is crucial to identify the priorities for restoration and provide useful information for future nature conservation and planning in Xishuangbanna.

The goals of this paper are to: (1) quantify BESs from 1976, 1990, and 2010 based on land-use dynamics; (2) identify and analyze conservation hotspots with high BES values for different years in Xishuangbanna; and (3) assess the impacts of LUC on multiple ecosystem services at the scale of both the study area and the sub-watershed. In this study, the InVEST model was
applied to calculate and visualize the quantitative changes in BES. Conservation priority analysis allows the identification of hotspot areas with high BES values within a landscape.

2 Materials and methods

2.1 Study area

Xishuangbanna (21°09'-22°36'N, 99°58'-101°50'E) is located at the very south of the Yunnan province, belonging to a transitional zone from tropical Southeast Asia to subtropical East Asia, which has rich biological diversity and typical rainforest ecosystem [36]. It borders Laos and Myanmar, and consists of Jinghong, Menghai, and Mengla Counties (Fig 1). The total area is about 19120 km², and the elevation varies from 474 m to 2429 m above sea level. The western and eastern regions are areas of higher elevation, while the central region is lower and extensively disturbed by anthropogenic effects. The region’s annual mean temperature is approximately 21°C and its annual precipitation is over 1500 mm.

2.2 Data sources

Three periods (1976, 1990 and 2010) were chosen for the InVEST model and two periods (1990 and 2010) were used to analyze the relationship between BES and landscape pattern. The land-use data were obtained from the Data Centre for Resources and Environmental Sciences, Chinese Academy of Sciences (http://www.resdc.cn/), and validated with an overall accuracy of at least 85% by the ground data. The land uses were classified into eight types: broad-leaved forest, coniferous forest, dry land, paddy field, artificial forest, residential area, shrub grassland and water. A Digital Elevation Model (DEM) data (100m) were provided by the International Scientific & Technical Data Mirror Site, Computer Network Information Centre, Chinese Academy of Sciences (http://www.gscloud.cn/) and were used to generate the sub-watershed map.

All data (or layers) needed in the process of the InVEST modeling are shown in S1 Table. Roads were classified as a national expressway, provincial road, county road, or rural road in our study. The resolution of all data layers was resampled as 100 m×100 m. Buffer distances around residential area and cities were set as 3 km and the relative sensitivity of each habitat

![Fig 1. Location of the study area.](https://doi.org/10.1371/journal.pone.0189368.g001)
type to each threat was identified. In addition, the data on water yield and the value of “carbon pools”, varying from one land use to another, were collected (S1 Table).

2.3 InVEST model

The InVEST model was used to calculate habitat quality, water yield and carbon storage in our study. Habitat quality is viewed as a proxy for biodiversity in the InVEST model (Significantly, “habitat quality” is not the same as “biodiversity”, as it doesn’t include species data) and is estimated by analyzing land cover in conjunction with related threats [9]. There are many rare species that depend heavily on forest and water resources in the tropical region. These different habitat types are treated equally and inputs are assumed to not focus on any particular species, but rather apply to general biodiversity in this model [9]. The formulas are as follows [9]:

\[
Q_{xj} = H_j \left(1 - \left( \frac{D_{xj}}{D_{xj} + k^z} \right) \right)
\]

\[
D_{xj} = \sum_{r=1}^{R} \sum_{y=1}^{Y_r} \frac{\omega_x}{\sum_{r=1}^{R} \omega_x} r_i A x r_y = \exp \left(- \frac{2.99}{d_{max}} d_{xy} \right)
\]

where, \(D_{xj}\) is the total threat level on pixel \(x\) for \(LU_j\); \(r\) presents the threat layer; \(Y_r\) indicates the set of grid cells on \(r\)'s raster map; \(Y_r\) and \(Y_{r+1}\) are the linear distance between grid cells \(x\) and \(y\); \(d_{max}\) is the maximum effective distance of threat \(r\)’s reach across space; \(Q_{xj}\) means the habitat quality of pixel \(x\) in \(LU_j\); \(H_j\) indicate the habitat suitability of \(LU\) type \(j\). Constant \(k\) is the half-saturation constant and \(z = 2.5\) is set as programmed. The final habitat quality values range from 0 to 1. The impact of threats on habitat is mediated by four factors: 1) \(\omega_r\) indicates the relative impact of each threat (value from 0 to 1); 2) \(i_{xy}\) indicates the distance between habitat and the threat source and the impact of the threat across space; 3) \(\beta_x\) is the factor that may mitigate the impact of threats on habitat through various protection polices (here \(\beta_x = 1\)); and 4) \(S_r \in [0, 1]\) indicates the sensitivity of \(LU_j\) to threat \(r\) where values closer to 1 indicate greater sensitivity, (if \(S_r = 0\) then \(D_{xj}\) is not a function of threat \(r\)).

The amount of water for each pixel was calculated based on the Budyko curve method and precipitation data at the sub-watershed scale in the model, and formulas of water yield are as follows [9,37]:

\[
Y(x) = \left(1 - \frac{AET(x)}{P(x)} \right) \times P(x)
\]

\[
\frac{AET(x)}{P(x)} = 1 + \frac{K(L_x)ET_0(x)}{P(x)} - \left[1 + \left(\frac{K(L_x)ET_0(x)}{P(x)}\right)^{\omega}ight]^{-1/\omega}
\]

\[
\omega(x) = \frac{AWC(x)}{P(x)} + 1.25
\]

where, \(Y(x)\) is the annual water yield for pixel; \(AET(x)\) represents the annual actual evapotranspiration; \(P(x)\) is the annual precipitation; \(k(L_x)\) is the vegetation evapotranspiration coefficient associated with the landuse \(L_x\); \(ET_0(x)\) is the reference evapotranspiration of pixel \(x\); \(\omega(x)\) the...
is a non-physical parameter to characterize the natural climatic-soil; $AWC(x)$ is the volumetric plant available water content (mm); and $Z$ parameter is a seasonality coefficient corresponding to the seasonal precipitation distribution.

Four carbon “pools” in terrestrial ecosystems (aboveground biomass, belowground biomass, soil, and dead organic matter) are included in the InVEST Carbon Storage and Sequestration model that is used to calculate the carbon storage of study area [9].

$$C_t = C_{\text{above}} + C_{\text{below}} + C_{\text{dead}} + C_{\text{soil}}$$  \(7\)

where, $C_t$ is the total carbon density (Mg/ha) for each pixel; $C_{\text{above}}$, $C_{\text{below}}$, $C_{\text{dead}}$ and $C_{\text{soil}}$ are the carbon density (Mg/ha) of aboveground biomass, belowground biomass, dead organic matter, and soil, respectively.

2.4 Hotspot recognition and Kernel Density analysis

Hotspots were defined first before overlapping and analyzing $BES$s. Usually, the percentage of top $BES$ values for a given area can be used to recognize the hotspots [38]. Given this, we abstracted the top 20% of each layer and overlaid them to gain the final hotspots, which further need to be clipped with the land use map to figure out which kinds of land-use have high ecosystem values in our study area. The Kernel Density of conservation hotspots was also recognized in ArcGIS 10.0 (search radius was set as 2500 m) to explore the general distribution characteristics of these hotspots.

2.5 Relationship between BES and landscape pattern

The temporal changes of $BES$ were quantified as follows [3]:

$$BESCI_x = \frac{BES_{\text{CUR}_x} - BES_{\text{HIS}_x}}{BES_{\text{HIS}_x}}$$  \(8\)

$$BESSI = \frac{\sum BESCI_x}{n}$$  \(9\)

$$BESSI_{\text{mean}} = \frac{\sum^m BESSI}{m}$$  \(10\)

where, $BESCI_x$ is the relative change index of each service $x$, and $BESSI_x$ is the total change of all the considered $BES$, both ranging from -1 to 1. $BES_{\text{CUR}_x}$ and $BES_{\text{HIS}_x}$ are the current and historical states, respectively, of service $x$ at times $j$ and $i$ (here, $j = 2010$, $i = 1990$). $BESSI > 0$ means the improvement of local ecological supporting system while $BESSI < 0$ indicates the degradation of local ecosystem state. $BESSI_{\text{mean}}$ is the average change value of $BES$ of each sub-watershed; and $m$ is the total number of pixels in a sub-watershed.

The landscape pattern indices—Patch Cohesion Index ($COHESION$), Landscape Shape Index ($LSI$), Number of Patches ($NP$), Perimeter-Area Fractal Dimension ($PAFRAC$), and Shannon’s Diversity Index ($SHDI$)—were chosen to represent the landscape pattern of the study area, and were calculated by the method of moving window (2 km) in Fragstats 4.2. Besides the $COHESION$, all of the other indices belong to the negative landscape indices which will increase in value if the degree of landscape integrity declines (or landscape fragmentation increases). The sub-watershed layer was generated by the use of ArcSWAT and resulted from DEM data that is available from NASA online. These catchments were classified into two classes (the negative group and the positive group) based on the average value of $BESSI_{\text{mean}}$. Then,
these two groups of catchments were taken as the statistical unit of aforementioned landscape pattern indices to explore the relationship between BES and landscape pattern, and to evaluate the hotspot change in terms of the landscape characteristics.

3 Results

3.1 Changes of BES and land use from 1976 to 2010

The artificial forest area in Xishuangbanna increased from $23.84 \times 10^7$ m$^2$ to $492.41 \times 10^7$ m$^2$, while the broad-leaved forest area decreased greatly by 31.4% from 1976 to 2010 (S2 Table). Most of the broad-leaved forests were converted to shrub grassland, artificial forest, and paddy field. Another two distinct changes of land use were the continuous growth of residential areas and paddy fields, and the declining trend of dry land. Spatially, land uses in the middle and west regions varied much more intensely than those in the east region where natural forest was dominant (S1 Fig). Changes in the distribution and quantity of three ecosystem services were also obvious (Fig 2). For habitat quality, Menghai County and Mengla County were much better than Jinghong County. Water supply service ranged from 284 mm to 1427 mm. Water supply values in the eastern and western parts were higher than those in the central part of the study area. Carbon storage was always high in the eastern region but reduced in the western areas gradually.

According to the land-use maps, high BESs were mostly concentrated on forest land and agro-forest land, suggesting that these land uses are critical for provisioning of the ecosystem services considered here. Comparatively, values of these services were lower in residential areas, especially in the central part of the region. Ecosystem service quantities in 1976 were

![Fig 2. Temporal variations of BES (a), (b), (c) are changes in habitat quality, water yield, and carbon storage respectively; (i), (ii), (iii) represents the years 1976, 1990 and 2010).](https://doi.org/10.1371/journal.pone.0189368.g002)
much higher than the ones in 1990 or 2010. As a whole, the region experienced a greater loss in BESs during the study period.

The BESCI index clearly showed the spatial variations of different services. Except for the carbon storage, the other two services increased little in quantity from 1990 to 2010 (Fig 3). The BESSI value ranged from -0.44 to 0.77, from which we found that only a few areas obviously increased in BES and most of them were distributed in the eastern region. There were 138 sub-watersheds distributed in Xishuangbanna and twenty-five percent of the sub-basins belonged to the negative group. However, most of the sub-watersheds remained relatively stable in BESs during this period.

3.2 Hotspot identification

Assessment of the cumulative status of BESs can generate a picture quite different from individual ecosystem service evaluation. The hotspots were recognized by overlaying biodiversity and the two basic ecosystem services, and further clipped by the corresponding land-use layers. Distributions of hotspots tended to be more scattered and the quantity of hotspots decreased greatly from $1.25 \times 10^5 \text{ ha}$ to $0.63 \times 10^5 \text{ ha}$, in total reduced by nearly 50% during thirty-five years (Table 1). Few hotspots were identified around Jinghong County, while most hotspots were located in the administrative region of Mengla County. However, the hotspot densities
also declined in the eastern region, and the high-density areas significantly decreased, especially in 2010 (Fig 4).

### 4 Discussion

#### 4.1 LU impacts on BES and hotspots

The habitat quality increased in the middle of the study area because of the extension of artificial forest which was also treated as a habitat in our study. Although artificial afforestation could have negative effects on forest biodiversity and natural connectivity compared with natural forests [39], the main purpose and function of plantation in deforested regions could contribute to land recovery and biodiversity protection to reduce ecological degradations to some extent [40,41]. As for Jinghong County, rubber was the main type of plantation and became the selective habitat of Asian elephant and intermediate habitat of some amphibians [42,43]. Because of the field-data limitation, only habitat quality from 1990 and 2010 were validated by animal occurrence records from previous studies [44,45]. Based on the data of local animal

| Land cover          | 2010          | 1990          | 1976          |
|---------------------|---------------|---------------|---------------|
| Broad-leaved forest | 11000.47      | 36831.32      | 52617.01      |
| Coniferous forest   | 377.78        | 4371.02       | 2781.97       |
| Dry land            | 353.31        | 1005.70       | 385.61        |
| Paddy field         | 1268.52       | 631.16        | 205.79        |
| Artificial forest   | 814.14        | 729.12        | 88.25         |
| Residential area    | 0             | 0             | 0             |
| Shrub grassland     | 49677.94      | 73446.11      | 68805.86      |
| Water               | 18.61         | 25.95         | 11.67         |
| Total area          | 63510.83      | 117040.39     | 124896.17     |

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Fig 4. Distributions of hotspots during the study periods ((a), (b) are the distribution and the Kernel Density of hotspots, respectively; (i), (ii), (iii) represent the year of 1976, 1990 and 2010).

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monitoring points, about 35% Asian elephant and 70% green peafowl occurred in the top 20% of habitat quality in 1990. For Asian elephant, this proportion was up to 42% in 2010 (S2 Fig). The main reason why the proportion of Asian elephants in the top 20% was less than 50% might be attributed to the fact that elephants may usually show up in dry land or residential areas which are not their suitable habitats [43]. Regardless, the results of BES for habitat quality can indicate the biodiversity levels in Xishuangbanna for certain species.

According to our results, high values of water supply occurred in the areas that were high in altitude and covered by shrub grassland, paddy fields or natural forests. The central part of the study area was low in water yield, because evapotranspiration is relatively high with decreasing vegetation coverage and increasing constructed areas. The annual precipitation change was not detectable for the whole region, but the changes in evapotranspiration are obvious because of the change of surface structures. Impervious surfaces, the typical land type affected by human activities, have relatively less ability to store water, but have a strong thermal storage capacity [46]. In contrast, approximately two-thirds of the total water yield was produced by grasslands and forest ecosystems. Referring to some previous studies [24,47], the results of our study also showed that abundant shrub or grass planting in the catchment can increase water yield and have positive quantified effects on the hydrological cycle. Besides these habitat types, the tropical rain forest also enhances the landscape resilience to hydrological change, and plays a significant role in water conservation [48,49].

Information about how much and where carbon is stored is vital to landscape management, and can be used by the government to decide the main use (for protection, harvest, or development) of targeted sites. Carbon storage in 1976 was much higher than in the other two periods, especially in the western and eastern regions covered by large areas of natural forest. However, storage quantities of carbon in the western areas, where broad-leaved forest was converted into shrub grassland or paddy fields, gradually declined during the study period. The biomass of artificial forest was much lower than that of local tropical natural forest, as well as the shrub grassland [50,51]. According to the BESCI index of carbon storage (Fig 3), we can detect the obvious increase in carbon stock which was caused by the plantation expansion in 2010.

Compared with other land cover types, broad-leaved forest and shrub grassland occupied the largest proportion of the hotspots. The percentage of broad-leaved forest decreased from 42.13% to 17.32% during thirty-five years; while the proportion of shrub grassland increased gradually, from 55.09% to 78.22% (Table 2). Because of the high altitude and surrounding paddy fields which increased the humidity of the surrounding air and reduced the value of

| BES                  | Ranking | 1990       | 2010       |
|----------------------|---------|------------|------------|
| Habitat quality      | 20%     | 81.06%     | 84.01%     |
|                      | 20–40%  | 4.56%      | 3.73%      |
|                      | 40%-100%| 14.38%     | 12.25%     |
| Standard Deviation   | 0.35    | 0.33       |            |
| Water yield          | 20%     | 20.27%     | 19.36%     |
|                      | 20–40%  | 18.32%     | 20.25%     |
|                      | 40%-100%| 61.40%     | 60.40%     |
| Standard Deviation   | 217.26  | 191.84     |            |
| Carbon storage       | 20%     | 81.55%     | 61.60%     |
|                      | 20–40%  | 4.57%      | 26.37%     |
|                      | 40%-100%| 13.89%     | 12.04%     |
| Standard Deviation   | 105.53  | 94.88      |            |

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the shrub grassland had high values and occupied an increasing proportion of hotspots in terms of the service of water yield. According to the definition, hotspots were the areas that belonged to the top 20% of each layer simultaneously. However, because the top 20% water yield had the smallest area percentage compared with the other services, the water yield service was found to be the limiting factor of hotspot identification in our study (Table 2). Moreover, the high standard deviation value of water yield showed that it had a high variability and spread out over a wider range. Surface differences between the residential areas and the broad-leaved forest are significant, leading to an obvious difference in water yield.

Further analyses that focused at the scale of sub-watersheds would be more meaningful to informing practice (like local landscape management, land-use planning, resource conservation and so on). According to our study results, from both 1990 and 2010, hotspots that were located in the sub-watershed whose BESSI > 0 were more than three times the ones located in the sub-watershed whose BESSI < 0. That is to say, most of hotspots were distributed in the areas with increased BES, suggesting that these sub-basins played a key role in safeguarding regional ecosystem services. Then, what about different kinds of sub-watersheds featured in the landscape characteristics that can describe the landscape pattern? We discovered that all the negative landscape indices (LSI, NP, PAFRAC, and SHDI) increased as BESSI < 0, indicating that affected sub-watersheds would suffer from landscape fragmentation and ecosystem services loss at the same time (Table 3).

### 4.2 Attention to certain hotspots

The National Nature Reserve in Xishuangbanna includes five national sub-reserves: Mangao (7870 ha), Mengyang (99840 ha), Menglun (10933 ha), Mengla (926833 ha), and Shangyong (31184 ha). However, all of these sub-reserves occupied only 15%–30% of the total hotspot areas during the thirty-five years. There are at least two main reasons for this result. On the one hand, contributions of five nature sub-reserves that were formally established in 1981, were not only based on the biodiversity state, but also in the light of related rules according to Regulations of the People’s Republic of China on Nature Reserves (http://www.gov.cn/flfg/2005-09/27/content_70636.htm). These reserves do not fully consider ecosystem services, since the BES theory had not been proposed until the 21st century [52,53] and the applications of BES came even later in China. On the other hand, the locations of reserves depend largely on actual situations, such as the growth of vegetation, animal distributions, social conditions, topography and so on. It is undeniable that all of these factors could not be adequately considered in one model. Due to these aspects, the deviations that occurred between hotspots and nature reserves cannot be ignored.

### Table 3. Changes of landscape pattern indices based on sub-watershed groups.

| Sub-watersheds | Landscape pattern index | 1990 | 2010 | The absolute change rate (%) | The relative change rate (%) |
|----------------|-------------------------|------|------|-----------------------------|-----------------------------|
| **BESSI mean < 0** | COHESION | 95.44 | 94.56 | -0.88 | -0.92 |
| | LSI | 2.41 | 2.62 | 0.21 | 8.74 |
| | NP | 8.98 | 11.25 | 2.27 | 25.32 |
| | PAFRAC | 1.35 | 1.36 | 0.01 | 0.52 |
| | SHDI | 0.71 | 0.84 | 0.13 | 18.37 |
| **BESSI mean > 0** | COHESION | 94.91 | 95.84 | 0.93 | 0.98 |
| | LSI | 2.56 | 2.2 | -0.36 | -14.02 |
| | NP | 9.99 | 8.65 | -1.35 | -13.47 |
| | PAFRAC | 1.37 | 1.34 | -0.03 | -1.91 |
| | SHDI | 0.77 | 0.63 | -0.15 | -18.97 |

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It is true that ecosystem service degradation can weaken the environment’s ability to support the diversity of livelihoods [54]. For the areas with high BES values, hotspots, especially those outside the nature sub-reserves, should be protected in advance and viewed as potential areas for further conservation. What’s more, about twenty-three percent of the hotspots are associated with the negative group ($BESS_{\text{mean}} < 0$). These hotspots are also sensitive to landscape fragmentation caused by human land use practices, and therefore need extra protection. So, land managers should pay much attention to these key areas. As a whole, in the eastern region in the Xishuangbanna prefecture, more conservation areas should be designated.

4.3 Limitations of BES in the study region
This study explored local ecological hotspots with limited ecosystem services as well as their temporal change. Habitat quality, water yield, and carbon storage were selected in our study, but there is a highly likelihood of deriving different results if different arrays of ecosystem services were chosen. Nevertheless, data deficiency prevented us from modeling all regional related ecosystem services available in the InVEST model. In addition, limitations of the InVEST model—its simplified modeling processes and inability to account for seasonal variability—cannot be ignored [55]. For example, the water module is unable to cover the full hydrologic cycle and the biodiversity index only focuses on habitat quality without considering species richness or other relevant indices of biodiversity [9]. Users should be aware of the uncertainties represented using this model and strengthen service simulations by field validation.

Hotspots mapped by overlaying different layers have represented key protected regions of biodiversity as well as other key ecosystem services in human dominated landscapes. What’s more, all the hotspots and areas with high values in each service have far-ranging policy implications in maintaining a sustainable eco-environment.

5 Conclusions
In Xishuangbanna, land cover changed significantly from 1976 to 2010 with the sharp decline of broad-leaved forest and the continuous increase of paddy fields, artificial forest and shrub grassland. Land-use type and structure dramatically affected $BES$ in different ways. Total values of ecosystem services (including habitat quality, carbon storage and water yield) decreased with time. Correspondingly, the hotspots with high $BES$ values shrunk and their distributions tended to be more scattered. At the sub-watershed scale, though most areas showed a stable trend in services, the values of $BES$ were generally high in eastern sub-watersheds compared with western ones. However, sub-watersheds that decreased in services included nearly a quarter of the hotspots, which were more sensitive to landscape fragmentation. The prioritized hotspot areas which were composed primarily of broad-leaved forest and shrub grassland were regarded as potential conservation areas in addition to the current sub-reserves. These hotspots can provide multiple ecosystem services that are beneficial not only to local species, but also to landscape sustainability.

Our methods make full use of readily available data; therefore, it is applicable to other areas or higher level regions for hotspots identification. A better understanding of land-use effects on biodiversity conservation is significant for ensuring sustainable growth of environmental protection and social development. In conclusion, this study provides sound information to locate Xishuangbanna hotspots and sensitive sub-watersheds, which is helpful to minimize the degradation of ecosystem services in future environmental conservation.
Supporting information

S1 Table. Data requirements for the three sub-models.
(DOCX)

S2 Table. The transfer matrix of land use areas from 1976 to 2010 (m²).
(DOCX)

S1 Fig. Land-use of 1976, 1990, and 2010.
(TIF)

S2 Fig. Validation of the habitat quality.
(TIF)

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