Mapping critical natural capital at a regional scale: spatiotemporal variations and the effectiveness of priority conservation

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Abstract

The spatially and temporally explicit mapping of critical natural capital (CNC) is an essential step toward supporting policies and practices for improving the CNC-derived human well-being. The Qinghai-Tibetan Plateau (QTP) is a natural habitat for wildlife and a critical water tower region for Asia. It is ecologically fragile, but still provides abundant CNC. The effectiveness of key protected areas in the QTP in terms of representing CNC remains largely unknown. In this study, we adapted a multi-criteria biophysical approach for CNC mapping from 2000 to 2015 that quantitatively integrates four CNC functional components, including carbon capture, soil protection, water and nutrient retention, and habitat provision. The CNC priority conservation areas and their conservation effectiveness are quantified based on CNC assessment and mapping. The results showed that: (1) CNC conservation priority areas accounted for 37.96% of the QTP, but only about one fifth accommodated in the national nature reserves (NNRs); (2) compared with the non-reserve areas and the whole QTP, NNRs have a better promotion effect on CNC with spatial heterogeneity; and (3) 60.81% of the core zones of NNRs showed a significant increase in CNC, which was 7.44% and 5.13% higher than those of the buffer area and the experimental area, respectively. The study contributes to the policy goals on the spatial optimization of nature conservation. Our method for assessing the CNC functional components can be easily adapted to broaden spatial scales, as well as for tasks such as conservation priority-setting or effectiveness assessments for protected areas with CNC as key targets.

1. Introduction

Given the rapid socioeconomic development and the high growth rates of human population, protecting important spaces for biodiversity and ecosystem function is a major challenge for land planning and management worldwide. All countries are now broadly aware of the need to take account of environmental issues in their policymaking (Paul et al 2003). The system of protected areas is an important means of management in order to protect biodiversity, preserve natural capital, maintain ecosystem services, and to safeguard the human wellbeing across the world. Currently, there are 202 467 protected areas globally, covering about 20 million km\textsuperscript{2}, or 14.7% of the planet’s land (de Castro-pardo et al 2020). After the establishment of the protected areas, assessing the effectiveness of the existing protected areas becomes an important task for the adaptive and sustainable protected area management. In order to do this, it is necessary to first identify and quantify what critical natural capital (CNC) we have protected, and how they have changed. Secondly, the priority areas for CNC conservation need to be identified. Finally, the
effectiveness of existing protected areas in terms of CNC conservation needs to be analyzed through a comparative analysis.

Ecosystems and natural resources that support human well-being are a form of capital, and thus are assets to society (Barbier 2013, Maher et al 2020). Natural capital refers to all types of environmental assets, including land, minerals and fossil fuels, solar energy, water, living organisms and the services provided by the interactions of all these elements on ecological systems (UNEP 2019). Critical natural capital (CNC), an essential and renewable subset of natural capital, is to highlight the very limited substitutability of the functions and services provided by natural capital as concerns their unique contribution to human well-being (Pelenc and Ballet 2015, Lü et al 2017). Previous studies have discussed the definition, protection strategy, evaluation method, and research directions of natural capital (Costanza et al 1997, Hinterberger et al 1997, Vassallo et al 2013, Daly 2020, Maher et al 2020, Randle-Boggis et al 2020, Tyler DesRoches 2020). Ecosystem services refer to the contribution that ecosystems make to the benefits received by economic units and people from the environment (UNEP-WCMC and IDEEA 2017). There is great concern about their assessment and valuation (Ouyang et al 2016, Liu et al 2019, 2020, de Castro-pardo et al 2020). The CNC quantification methods as related to soil ecosystem (Brady et al 2015, Hewitt et al 2015), marine ecosystem (Vassallo et al 2013), forest ecosystem (Maher et al 2020), reservoir areas (Zhang et al 2020), parks (Randle-Boggis et al 2020) have been extensively studied in previous research.

Some ecosystem services (i.e. carbon capture, soil protection, water and nutrient retention, and habitat provision) can be taken as functional components of terrestrial ecosystems and represent biophysical aspects central to the generation of CNC (Lü et al 2017). The functional components of terrestrial ecosystems reflect the role of vegetation and soil in the so-called critical zone of the earth’s surface, which contributes to sustainable human well-being. The net primary productivity (NPP) of vegetation provides the energy that underpins nearly all terrestrial ecosystems, and is a key functional indicator (Zhang et al 2017). NPP supports the ecosystem function and is linked with the overall value of ecosystem services (Costanza et al 1997). Therefore, previous studies chose NPP as an important model parameter with which to quantify CNC functional components (Carreño et al 2012, Lü et al 2017). The NPP can be estimated by combining a remotely sensed vegetation index with other pertinent environmental variables in order to reveal spatial and temporal characteristics at the regional scale (Potter et al 1993, Zhu et al 2007, Lü et al 2017).

The Qinghai-Tibetan Plateau (QTP) covers the entire Tibet Autonomous Region and Qinghai Province, in addition to parts of Sichuan, Yunnan, Gansu, and Xinjiang. Due to its high altitude and large geographical area, the QTP plays a significant role in the Earth’s climate system, with its unique and complex interactions of atmospheric, cryospheric, hydrological, geological, and environmental processes bearing a large effect on the Earth’s biodiversity, climate, and water cycles (Jin et al 2005, Yao et al 2012). The QTP provides a significant amount of crucial CNC to Asia and around the world. Ecological restoration and conservation progress in the QTP has a vital bearing on sustainability in and beyond the region.

Reasonable evaluation of the effectiveness of ecological conservation is of great significance for regional conservation planning and management. This study seeks to address the issue of conservation effectiveness by quantifying and comparing CNC at a regional scale. Here, we combine ecological process indicators with topographic factors, meteorological factors, and soil properties in order to construct a composite CNC index, making it much easier to quantify the relative capacity of terrestrial ecosystems to provide CNC and evaluate the effectiveness of regional CNC conservation. A single indicator not only contains the information of multiple CNC functional components, but also is easier to be used in ecological management decision making. In doing so, the study provides a deeper understanding of the effectiveness of CNC priority conservation and the effect of the protected areas. Focusing on the QTP, the objective of this study is to (a) quantify the spatio-temporal characteristics of the CNC; (b) identify priority areas for CNC conservation; and (c) examine the effectiveness of CNC priority conservation.

2. Study area and methods

2.1. Study area

Located in Southwest China, the QTP reaches elevations (mean 4000 m) higher than any other plateau worldwide (figure 1), and extends over 2.5 million km² (Wu et al 2017). The QTP is a large region with a land mass equals to about 1/4 of USA or five times bigger than that of France. It is often referred to as ‘the Roof of the World,’ ‘the Asian water tower,’ and ‘the Third Pole,’ and it has received considerable research attention (Yao et al 2012, Li et al 2018). The annual average precipitation and temperature are 413.6 mm and 1.61 °C, respectively. Alpine grassland is the major ecosystem in the QTP, playing an important role as a shelter for eco-safety, and also serving as the basis of highland animal husbandry. The QTP is a natural habitat for rare wild animals and a gene pool of plateau life, as well as a key ecologically critical region in China for the drive to promote ecological civilization (The State Council Information Office of the People’s Republic of China 2018). The plateau is also one of the areas of the world where humans have
had a relatively minor impact. In 1963, the QTP designated its first national nature reserve. To date, the QTP has established 155 nature reserves in total at all levels (41 national and 64 provincial), covering a total area of 822,400 km². This accounts for 31.63% of the plateau's landmass, and represents 57.56% in area of China's terrestrial nature reserves (The State Council Information Office of the People’s Republic of China 2018). The plateau provides ideal conditions for investigating CNC and the effectiveness of nature conservation (Zhang et al 2007).

2.2. Quantifying functional components of CNC

In this study, we chose four functional components of the CNC (carbon capture, soil protection, water and nutrient retention, and habitat provision). This selection of functional components was based on the importance of vegetation and soil in the critical zone of the QTP. The four functional components each represented biophysical aspect central to the generation of CNC (Lü et al 2017). These four functional components were also chosen as they represent some of the most relevant issues for the QTP in particular, as the highest and ecologically fragile plateau in the world. For example, associated climate change and human pressures threaten habitat security, as well as the means of protecting soil and freshwater that relate to human well-being. The layer plays key functional roles in areas such as climate regulation, nutrient cycling, and habitat maintenance in the ecologically vulnerable region. We adapted and revised a biophysical approach from Carreño et al (2012), Barral and Oscar (2012), and Zhang et al (2017) in order to quantify the four CNC functional components (table 1). Based on this surrogate biophysical approach, a series of indices were used to quantify the CNC components in every pixel (250 × 250 m): net primary productivity, soil infiltration capacity, soil erodibility factor, slope, precipitation, temperature, elevation, and surface roughness. The carbon capture of vegetation was mapped using the NPP and its variations within a single year. The soil protection capacity was assessed using the NPP, NPP variations within a year, a soil erodibility factor, and slope. In addition, the water and nutrient retention was mapped using the NPP, NPP variations within a year, soil infiltration capacity, annual precipitation, and slope. Finally, the habitat provision
capacity was assessed using the NPP, NPP variations within a year, land surface roughness, annual precipitation, and temperature.

The product of NPP was derived from MODIS imageries with a ground resolution of 250 m from 2000 to 2015 during a 160 d time interval, based on the CASA (Carnegie-Ames-Stanford) ecosystem model. The slope and altitude were calculated from the STRM 90 m resolution digital elevation data (www.gscloud.cn) using ArcGIS 10.2. And the land surface roughness \((F_{sr})\) was calculated using the DEM based on the equation:

\[
F_{sr} = \frac{1}{\cos \theta}
\]

where \(\theta\) is the radian of the slope angle.

The soil erodibility factor \((K)\) was calculated from the EPIC (Erosion-Productivity Impact Calculator) equation \((\text{Zhang et al. 2017})\):

\[
K = \left\{ \begin{array}{ll}
0.2 & + 0.3e^{[-0.0256a(1 - 0.5)]}
\end{array} \right\} \left( \frac{s_i}{C + s_i} \right)^{0.3}
\]

\[
\times \left\{ \begin{array}{ll}
0.25 & - \frac{0.7}{C + 0.7} + 0.25C
\end{array} \right\}
\]

\[
\times \left\{ \begin{array}{ll}
0.7 & 1 - \frac{a_{\text{c}}}{100} + e^{(-5.51 + 22.91 - \frac{0.6}{3.7})}
\end{array} \right\}
\]

(5)

(6)

The soil infiltration capacity \((F_{sic})\) was quantified according to the 13 soil texture classifications from clay to sand based on the soil texture map of China (from the China Soil Map-based Harmonized World Soil Database 1.1, http://westdc.westgis.ac.cn). The annual average precipitation and temperature were calculated and interpolated using the data downloaded from the National Meteorological Information Center, China Meteorological Administration (http://data.cma.cn). The above variables used in calculating functional components (apart from \(F_{sic}\)) were standardized between 0 and 1 using the Min-Max method (Lü et al. 2017). The overall CNC index \((CI)\) was formulated as following equation:

\[
CI = 1000 \times \sum CNC_i
\]

(7)

where \(CI\) values range from 0 to 1000; \(CNC_i\) is the \(i\)th functional component \((n = 4)\) of CNC.

In the study, the spatial pattern of CNC was characterized by calculating the annual average value of \(CI\), and the \(CI\) was calculated using ArcGIS 10.2. The index was categorized into five classes (i.e. very high, moderately high, intermediate, low, and very low) using the quantile classification method. Additionally, linear regression was used in order to detect trends in CNC and calculated by least-squares regression model in MATLAB 2017b for temporal variations analysis.

2.3. Identifying CNC conservation priority areas

In order to further analyze the role of protected areas in the conservation of CNC, we identified the priority areas of CNC conservation. The \(CI\) was calculated first and mapped across the whole QTP, and then croplands and built-up land were excluded. The above step was aimed to exclude the impact of the human-dominated landscape. Finally, CNC conservation priority areas were identified by overlaying the moderately high and very high categories from the \(CI\) maps. In the study, the conservation priority areas were overlaid with the boundaries of the 41 national nature reserves (NNRs) in the QTP by 2017, and the overlaying results can demonstrate the current situation of CNC conservation. The NNR data was supported by the Nanjing Institute of Environmental Sciences, Ministry of Ecology and Environment of the People’s Republic of China.

2.4. Effectiveness analysis

Based on the results of CNC spatiotemporal variations, we compared the characteristics of the CNC between the NNR and other regions in the QTP using the spatial analysis function of ArcGIS 10.2. The proportion of the CNC area having significantly increased or decreased was calculated as an indicator, and it was easy to compare and analyze the trends of the CNC change in the different regions. In addition, we also extracted different types of NNR areas (i.e. core zone, buffer zone, and experimental zone), and analyzed their role in the conservation of CNC. In China, the core zone is where the natural ecosystems in the protected area have not been or have rarely been interfered with by humans, or areas that have been damaged but are expected to gradually recover.
The buffer zone refers to the area surrounding the core zone. Only scientific research and observation activities are allowed in the buffer zone, while the experimental zone is a multi-purpose area located around the buffer zone. In the experimental zone, people can engage in scientific experiments, teaching internships, visits and inspections, tourism, domestication, and the breeding of rare and endangered wild animals and plants, among other activities. There can also be a certain range of production activities in the experimental zone, as well as a small number of residential areas and tourist facilities. The effectiveness of CNC conservation was depicted through the analysis of the above NNR zones.

3. Results

3.1. Spatiotemporal variations of CNC

The overall spatial patterns show increasing CNC trends from the northwestern to the southeastern parts of the QTP (figure 2(a)). The very low value area of CNC is primarily distributed in the north and northwest of the QTP, while the low value area of CNC is mostly distributed in the west and north central areas. The areas with very low and low CNC values accounted for 14.46% and 21.03% of the total area of the QTP, respectively. The CNC value in the northeast and the northwest of the QTP is in the middle level. The eastern, southeastern, and central regions with the very high and moderately high CNC account for 37.96% of the total QTP area.

The annual CI index decreased in the west and southwest of the QTP, and the proportion of significant decrease areas and not significant decrease areas was 4.49% and 14.19%, respectively (figure 2(b)). In the northern, eastern, and central regions of the QTP, CNC has increased significantly, accounting for 52.8% of the total area. Overall, CNC in most QTP areas have increased significantly in the last 15 years, and the trends of CNC show obvious regional differentiation.

3.2. Identification of CNC conservation priority areas

Overall, 37.96% of QTP’s total land territory (2.55 million km$^2$) was quantified as CNC conservation priority areas (i.e. overall CNC representativeness), within which 20.24% (0.20 million km$^2$) existed in NNRs. In addition, in terms of regional distribution, the CNC conservation priority areas were primarily distributed in the south of the southwest–northeast line of QTP (figure 3). The eastern and southeastern CNC conservation priority areas were the most concentrated. Further analysis showed that 27.81% of the NNR region covered the CNC priority conservation area. The value was lower than that of non-reserve zone (i.e. 44.65%) and lower than that of the entire QTP.

3.3. Effectiveness of CNC priority conservation

The total area of the 41 NNRs is about 715 000 km$^2$. Taking all NNRs of the QTP as a whole, the proportion of regions in which CNC increased significantly from 2000 to 2015 was 55.34%, which was higher than that in non-reserve regions (54.16%) and the entire QTP (54.49%) (table 2). However, the average value of the significant increase rate of 41 NNRs was smaller than that of non-reserve areas and the entire QTP, indicating that there were regional differences in the effectiveness of NNR’s protection of CNC. NNRs such as Gansu Lianhua Mountain and Liancheng have a higher proportion of CNC growth, which shows that these NNRs play a significant role in improving the CNC. However, there are also some NNRs where CNC has not been significantly improved, such as Lalu Wetland and Baishuijiang NNRs. On the other hand, for the proportion of the area in which CNC has significantly decreased, the overall value and average value of NNR were 3.77% and 3.73%, respectively.
which were lower than those of non-reserved areas (4.69%) and the entire QTP (4.43%).

NNR, national natural reserve; Non-reserve area, areas other than NNRs; QTP, Qinghai-Tibetan Plateau; Sum, the overall value of NNR; and Mean, the average of 41 NNRs.

In order to further understand the effectiveness of CNC conservation within NNRs, this study analyzed the different zones of NNRs (i.e. core zone, buffer zone, and experimental zone) (table 3). A statistical analysis showed that 60.81% of the core zone experienced a significant increase in CNC from 2000 to 2015, which was higher than both the buffer zone (53.37%) and the experimental zone (55.68%). Except for the buffer zone, the proportions of CNC increase in other NNR zones are significantly higher than those in non-reserve areas (54.76%). In addition, the significantly decreasing area ratio of CNC in the core zone, buffer zone, and experimental zone were 3.28%, 4.4%, and 3.87%, respectively. All three were lower than the value of non-reserve areas (4.74%). On the other hand, there were some areas in NNR where the CNC showed no significant changes. Specifically, the ratios of the increased area of CNC in the core zone, buffer zone, and experimental zone were 26.65%, 28.51%, and 26.44%, respectively, which were all higher than the non-reserve area value (25.63%). At the same time, the proportion of the not significantly decreasing CNC areas in NNRs was lower than the value of non-reserve areas (14.86%).

4. Discussion

4.1. Representation and effectiveness of CNC conservation

We used a biophysical approach in order to quantify and spatialize the QTP CNC conservation priority areas, which was an important basis for the representation and effectiveness assessment of the NNRs. The results showed that 20.24% of the CNC conservation priority areas were distributed in NNRs. In the NNRs, less than one third of the areas were CNC conservation priority areas, which was lower than non-protected areas (44.65%) and also lower than the entire QTP (37.96%). In the study, we detected relatively large gaps in the representativeness of CNC conservation priority areas (figure 3), despite previous studies indicating that national natural reserves in China were effective at mitigating vegetation degradation (Lü et al 2015, 2017). The reasons for this situation might be the fragmented management of these different NNRs (Wu et al 2011, Xu et al 2017, Jantke et al 2018) and the insufficient consideration of the functional roles of CNC in planning and establishment of NNRs (Lü et al 2017, Xu et al 2017). Our results also partly indicated that the current quantity and spatial allocation of NNRs falls short of meeting the needs of covering the CNC conservation priority areas (figure 3). Another possible reason was that the complex interaction between CNC and the ecosystem and environment is constantly changing (Anderson et al 2009). Based on the representation...
of the current NNRs, the NNR networks should be appropriately expanded in order to better implement protection actions and to mitigate the reduction or destruction of the CNC of the QTP. Mcdonald and Boucher (2011) analyzed the global networks of protected areas and found that the protected areas in some regions were underrepresented by means such as scenario prediction, proposing that the scope of the protected areas should be expanded, which is consistent with our research. More specifically for China, Xu et al (2017) used a model to quantify key ecosystem services combined with biodiversity indicators in order to identify conservation priority areas. Their results are 75% spatially consistent with the results of this study. On the other hand, for areas like QTP, where the population is small, and the economy is not well-developed, expanding the NNR networks requires both scientific planning and economic support, especially the support of national funds. There are many existing studies on how to coordinate the relationship between economic development and CNC protection, which still needs to be carried out according to the local situation (Dinda 2004, Dan et al 2006, Ram et al 2009, Mcdonald and Boucher 2011). More in-depth and regionally targeted research is needed in the future.

Determining how to adjust the scope and the number of NNRs in the future requires the comprehensive consideration of protection effectiveness. For managers, effectiveness is an important basis for the implementation of management strategies. The results of the study showed that the effectiveness of CNC increase in NNRs was greater than that in non-reserve areas and the whole QTP (table 2). Furthermore, the effectiveness of CNC increase in the NNR core zone and the experimental zone was better than that in non-reserve areas (table 3). In addition, NNRs were better than non-reserve areas in terms of avoiding CNC reduction. The above results showed that the NNR, as the strictest protected area in the QTP, played an important role in promoting CNC. However, no statistically significant effectiveness was found, and there were differences in CNC promotion between the NNRs (table 2). One possible reason was that the study primarily focuses on CNC changes, but did not consider the difference of objectives that were initially established by NNRs. For example, if an NNR is dedicated to the protection of rare wild animals, its CNC is not necessarily very high, but it still may have high animal conservation effectiveness. As to the environmental background for the QTP, NNRs represent the most remote and climax ecosystems of the region. For the areas beyond the NNRs, the main differences are slightly increased human disturbances at regional scale such as livestock grazing which degraded the CNC but not very significantly. Although the ecosystem and its functions are affected by many factors, and the mechanism is very complex (Benayas and Bullock 2009, Li et al 2018, Zhang et al 2020), it has become a consensus that ecological protection is the main and most important means of biodiversity and ecosystem service improvement (Stige and Kvile 2017). This study showed that, spatially, there were more CNC priority conservation areas in the eastern and southeastern regions of the QTP, which were not included in the NNRs (figure 3). We proposed to expand conservation measures in the above areas in order to better cover the identified CNC conservation priority areas. In addition, the core zone in NNRs had an obvious effect on slowing down CNC degradation and promoting CNC improvement, but the buffer zone has a weaker effect on CNC improvement than the non-reserve area (table 3). Therefore, the spatial pattern of different NNR zones could be adjusted according to the conservation effectiveness of CNC, and the current management measures should be checked in order to analyze the reasons for the above results.

4.2. Utility of the CNC evaluation approach and policy implications

Ecosystem services that constitute a bridge between ecology and the economy (Brady et al 2015) are a key tool for the evaluation of natural capital. Previous

| Type of change | NNR (%) | Non-reserve area (%) | QTP (%) |
|----------------|---------|----------------------|---------|
| Sum | Mean | |
| Significant increase | 55.34 | 45.51 | 54.16 | 54.49 |
| Significant decrease | 3.77 | 3.73 | 4.69 | 4.43 |

| Type of change | Core zone (%) | Buffer zone (%) | Experimental zone (%) | Non-reserve area (%) |
|----------------|---------------|-----------------|-----------------------|---------------------|
| Significant increase | 60.51 | 53.37 | 55.68 | 54.76 |
| Significant decrease | 3.28 | 4.40 | 3.87 | 4.74 |
| Not significant increase | 26.65 | 28.51 | 26.44 | 25.63 |
| Not significant decrease | 9.56 | 13.73 | 14.01 | 14.86 |
studies have indicated that the assessment of ecosystem services in protected areas makes it possible to quantify the natural capital in an efficient manner, because the relative importance of ecological services in these places are greater than in other places (Naidoo et al 2008, de Castro-pardo et al 2020). The present study used a biophysical approach in order to quantitatively evaluate four CNC functional components for spatiotemporal pattern and trend analysis. Compared with some methods based on complex social-biological processes or monetary valuation, the approach requires less data, and the evaluation process is not complicated, nor will it lead to erroneous guidance due to the complexity of the socioecological systems based on monetary evaluation (Daly et al 2007). In addition, most of the data required by the approach can be obtained from remote sensing data and positioning monitoring in order to evaluate the CNC of the grid, making the approach easier to focus on spatial patterns and temporal changes, so as to better support land use and ecological conservation decisions (Lü et al 2017). On the other hand, at the regional scale, the approach mainly reflects the relative rankings of CNC, rather than accurate CNC values. Although it is difficult to accurately quantify CNC values, it is sufficient to meet the needs of decision-making and management for protected areas in perspectives of CNC spatial differentiation (Zhang et al 2017). Lü et al (2017) used the approach in order to identify China’s CNC priority conservation, and the results showed a strong consistency with the results of other complex methods (Yu et al 2009, Wu et al 2014, Xu et al 2017). The easy accessibility of data and the cross-scale adaptability of the indicators have enhanced the method’s general applicability in land use planning and policy development, ecological conservation assessment, and protected area management. For example, the approach can be used in the trade-off analysis between CNC functional components and the economic benefits produced by changes in land-use policies (Carreño et al 2012, Zhang et al 2017). In addition, previous studies in the pampas of southeastern Argentina have evaluated CNC functional components on land use planning and management using a similar approach (Barral and Oscar 2012). Therefore, the composite indicator-based assessment and mapping approach can be easily transferred to other large regions for policy evaluation and conservation decision support.

In China, ‘the development of ecological civilization’ has risen to become a core national strategy, emphasizing the need to ‘establish the concept of natural capital’ and to ‘promote urban and rural natural capital to accelerate value addition,’ which necessitates natural capital evaluation as a crucial scientific and policy relevant issue (Ouyang et al 2016, Zhang et al 2020). The QTP bears multiple tasks of ecological civilization and economic development, while CNC conservation is more important in the ecologically fragile context. Considering the needs of rural revitalization and ecological civilization in the QTP, determining how to coordinate the relationship between ecological conservation and economic development will be a crucial issue for the QTP. The establishment of a national park system in the QTP is a strategic choice for the QTP to innovate ecological civilization (Fan et al 2019). In addition, national park policy transition is a key decision in order to improve the local economic situation and to rationally use ecological resources (Xu et al 2019). Both national park planning and nature reserve planning need to rely on the quantitative verification of CNC. Therefore, the approach is needed in the study can provide important support for follow-up ecological planning in the QTP. The study identified CNC priority conservation areas and CNC low value areas (figure 2(a)). Combined with CNC change trends, it can facilitate the determination and division of the scope of national parks and new NNRs. In addition, some pilot national parks are based on existing NNR scopes and conservation goals (Fan et al 2019). Determining how to accurately and quickly carry out a background ecological data survey is one of the key factors in coordinating the development of ecological civilization and economy. Although the approach has its advantages in protected areas adjustment and decision support, it also has some limitations. For example, the research results are more about classifications or spatial rankings based on regional quantitative assessment of CNC, but the method cannot quantify the accurate biophysical or economic value of the CNC in question. We suggest using the advantages of the CNC quantification method in our study, such as the low data requirements and the ease of rapid CNC ranking analysis, in order to facilitate the process of ecological conservation planning and assessment in large geographical regions.

5. Conclusions

The management of protected areas faces the challenge of assessing their effectiveness on ecological conservation. The identification of priority conservation areas can help to facilitate the decision-making processes in the planning and management of protected areas. In the present study, we quantified and mapped the CNC of QTP for 2000–2015 with a biophysical composite indicator-based approach. Subsequently, CNC priority conservation areas were identified spatially. Finally, the effectiveness of CNC priority conservation of the NNRs was evaluated. The spatial pattern of CNC of QTP showed obvious regional characteristics, and the CNC in the east and southeast was superior to that of other regions. NNRs had a certain effect on CNC promotion, but there was
a relatively large gap in the coverage of CNC priority conservation areas in the current NNR system. The biophysical approach in the present study is readily transferable to other regions for facilitating conservation assessment and planning. Coupled with protected area management, the biophysical approach could also be embedded within planning and environmental policies in order to protect the natural capital under changing socio-ecological environments across spatiotemporal scales.

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Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

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