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Changes in Light Pollution and the Causing Factors in China's Protected Areas, 1992–2012

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Received: 30 August 2017; Accepted: 2 October 2017; Published: 5 October 2017

Abstract: The natural nighttime light environment of the earth has been significantly transformed by human activities. Such "light pollution" has a profound influence on ecosystems. Protected areas (PAs) play key ecological functions and are only effective at low light pollution levels or without any light pollution. In China, with rapid population growth and high urbanization rates, light pollution in PAs continues to aggravate and threaten a number of ecosystems. We used calibrated nighttime light images to study spatial-temporal changes in light pollution in China's PAs from 1992 to 2012 by classifying light pollution into three levels (moderate, medium, and strong). The results showed that in China's PAs, the area subject to light pollution increased by about 1.79 times, with a significant increase in the intensity of artificial light. The changes in light pollution exhibited significant regional differences. In the eastern developed regions, light pollution was more significant than that in other regions and the situation in East China was the most severe. In the Qinghai-Tibet, although light pollution was less significant, the area subject to light pollution increased significantly over the evaluated period. Factors influencing light pollution were also analyzed. Light pollution in a PA is influenced by both human activities and its own characteristics.

Keywords: China; light pollution; DMSP/OLS data; protected areas

1. Introduction

Human activities have transformed the natural nighttime light environment across large areas of the globe. Natural intensities, spectra, and cycles of light have been modified by artificial light, including public street lighting, advertising, public and private buildings, and vehicles, as well as sky glow, which is produced by upwardly emitted and reflected electric light being scattered by water, dust, and gas molecules in the atmosphere [1]. In 1996–1997, about two-thirds of the world population lived in areas where the night sky was characterized as polluted [2]. Both the extent and intensity of artificial light continue to increase with the rapid development of urbanization and industrialization.

Although the wide use of artificial light at night has significantly improved the quality of human life, the change in nighttime light environment has a profound influence on ecosystems; for this reason, we refer to the term "light pollution" [3]. Directly, it represents a threat to biodiversity [4] and can alter species distribution, community structure, and, possibly, ecosystem functions and processes [5]. Indirectly, light pollution has strong synergies and interactions with other pressures on biodiversity, including habitat fragmentation and climate change [6].

Protected areas (PAs) perform key ecological functions and are crucial for biodiversity conservation. Spatial patterns of wilderness are strongly influenced by human activities [7], while conserved habitats can, to some extent, buffer anthropogenic pressures and provide refuge for some species. However, PAs are only effective when they stop habitat loss within their boundaries and when they are connected to other wild areas via corridors [8]. Artificial nighttime lighting can effectively reflect human activities [9,10] and has strong effects on the ecosystem itself; therefore, it is a good indicator to measure the conservation efficiency of protected areas. Generally, when a protected area functions well, there is no or only slight light pollution.

China is the country with the largest population and is currently undergoing rapid economic development and urban expansion [11–13]. From 1992 to 2012, China's gross domestic product increased by about six times, while the country´s urban population increased from 320 to 700 million (National Bureau of Statistics of China 2016). As a result, China's total nighttime lighting has significantly increased [14], causing considerable light pollution. To protect its biodiversity, China has established 2640 nature reserves by 2011, covering 15% of its landmass [15]. This raises the question about the impact of rapid economic development and urbanization on light pollution in PAs. However, although studies on light pollution in protected areas have been undertaken on a worldwide scale [1,16], studies about light pollution in China were not enough and the previous studies mainly focused on urban areas [17]. Thus, light pollution in China's PAs needs to be studied urgently to help protect the wild environment. In addition, with an area of 9.6 million km^2, the country's regions differ widely in terms of economic development and natural geographical features; consequently, light pollution in PAs might be different in different regions. In this context, we evaluated the differences in light pollution in PAs by dividing China into different regions and focusing on both the scope change of the PAs affected by artificial night lighting and the light pollution level change in PAs.

2. Materials and Methods

We downloaded 21 yearly (1992–2012) nighttime average light composite images from the Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) provided by the NOAA National Geophysical Data Center [18]. In previous studies, the distribution of artificial light from these images has been used as a proxy for urbanization [9,19,20], population density [21,22], economic activity [23,24], as well as to assess the spatial extent of light pollution itself [2,25]. The images have a 30 arc second resolution and exclude the occasional effects of clouds and flares. Each pixel is represented by a digital number (DN) from 0 to 63. Zero represents darkness, whereas very brightly lit urban areas typically saturate at a value of 63.

For delineation of China's protected areas, the full World Database of Protected Areas (WDPA) data set was downloaded in October 2016 [26] and clipped at the Chinese border. The WDPA is the most comprehensive global spatial dataset on marine and terrestrial protected areas available. Protected area spatial data are collected in the form of a boundary (polygon) wherever available or as a single latitude and longitude coordinate (point) data where boundary data is not available [27]. For point data, a spatial approximation was built by creating a circular buffer around the points in accordance with the reported area of the site provided by the WDPA. To avoid over-counting overlapping PAs, the "dissolve" command in ArcMap was used to create a consolidated set of polygons that distinguishes areas under protected status from unprotected areas.

The land-use maps were derived from Landsat Thematic Mapper (TM) satellite images from 1990 and 2010 at a scale of 1:100,000, provided by the Resources and Environment Data Center of the Institute of Geographic Sciences and Natural Research, CAS [28]. Rural population numbers of counties in Shanxi were derived from Shanxi Statistical Yearbook [29,30].

No onboard calibration of nighttime light sensors exists, and the time series of this paper include data from six different satellites with different sensors. This means that the DNs within the images must be carefully cross-calibrated to reduce differences between the images [31,32]. Since China's PAs are mostly situated in rural regions [33], this study used the improved method of Tan [13] to rectify the nighttime light data, as this method is focused on China and selects a large number of reference points in rural regions to improve accuracy and consistency of the data from rural areas. In contrast, other methods mainly focus on urban areas. Although the DMSP data were calibrated, there were still fluctuations between different years, leading to an inaccurate estimation of the light pollution change trend from year to year. Thus, we divided the study time series into five sub-periods (1992–1995, 1996–2000, 2001–2004, 2005–2008, and 2009–2012) and used the average DMSP images of each sub-period to estimate the change trend.

To obtain nighttime light data of protected areas, we converted protected area data from polygon to binary raster data (i.e., featuring 1-values for PAs and 0-values for all other areas) and multiplied them with the DMSP data. Considering regional differences in economic development and nature geographical features, we divided mainland China into nine parts: Northeast China, North China, East China, Central China, South China, Inner Mongolia, Northwest China, Southwest China, and Qinghai-Tibet (Figure 1). Qinghai-Tibet and Inner Mongolia were separated because they cover large areas and show characteristics different from those of the other regions. Subsequently, we studied the scope change and intensity change of light pollution in the nine regions, using the following method and the workflow of this paper is illustrated in Figure 2.

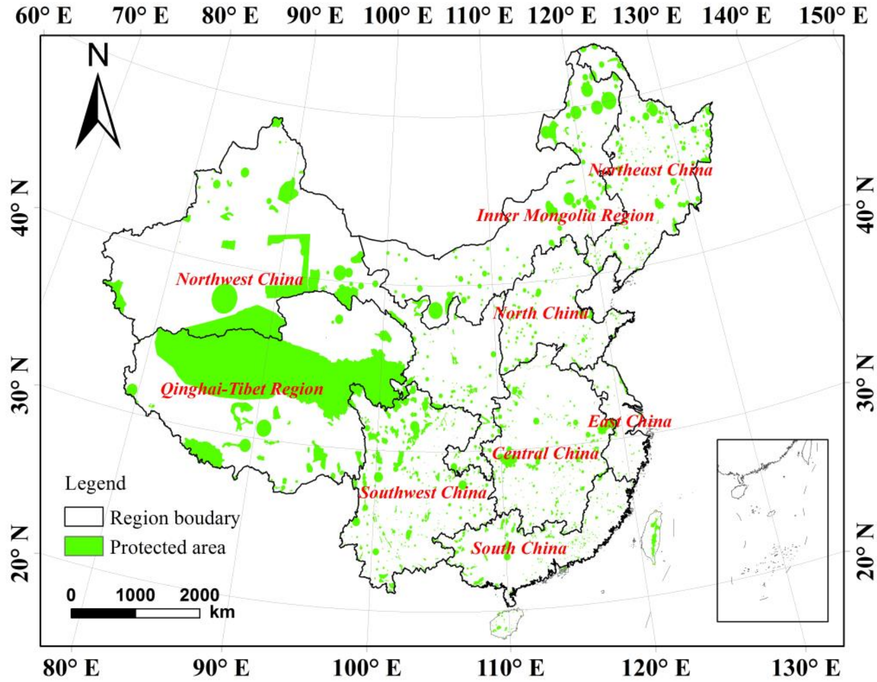

Figure 1. Spatial distribution of protected areas in different regions of China. The source of spatial distribution of protected areas is from the World Database of Protected Areas (WDPA) data set and provided by IUCN and UNEP, which can be downloaded from https://www.protectedplanet.net.

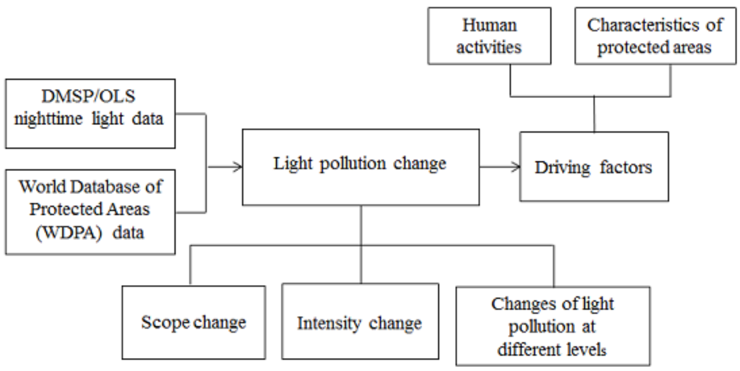

Figure 2. Flowchart showing the procedure of this study.

Considering overglow effect of nighttime light, we considered the pixels with a DN value above 5.5 as lit pixels that were affected by artificial light [1]. The proportion of lit pixels in protected areas (POLP) of a region can be used as an indicator to reflect the scope of the PAs with light pollution, which enabled comparisons between different regions with different areas. POLP is calculated using the following equation:

$$POLP_{ij} = \frac{Area_{litij}}{Area_{totalij}}, \quad (1)$$

where $POLP_{ij}$ is the proportion of lit pixels in protected areas of region i in the jth sub-period; $Area_{litij}$ is the area of lit pixels in in protected areas of region i in the jth sub-period; and $Area_{totalij}$ is the total area of protected areas of region i in the jth sub-period.

Subsequently, both the absolute change (used to compare different regions) and the relative change (used to compare a region with itself) of POLP from the first to the fifth sub-period were calculated to explore the scope change of light pollution during the period:

$$Abs.Change_i = POLP_{5i} - POLP_{1i}, \quad (2)$$

$$Rel.Change_i = \frac{POLP_{5i} - POLP_{1i}}{POLP_{1i}}, \quad (3)$$

where $Abs.Change_i$ is the absolute change of POLP in region I, $Rel.Change_i$ is the relative change of POLP in region i, $POLP_{1i}$ is the POLP of region i in the first sub-period, and $POLP_{5i}$ is the $POLP$ of region i in the fifth sub-period.

Brightness can reflect the intensity of light pollution. Firstly, to explore the general intensity change of light pollution (i.e., how many pixels were aggravated in light pollution and how many were mitigated), we used the average DN value of nighttime light data of the fifth sub-period minus that of the first sub-period and calculated the proportions of pixels increasing in brightness (DN change > 3) and decreasing in brightness (DN change < 3), respectively, while those pixels with a DN change below 3 were considered as being subject to no change [34].

Secondly, to explore the changes in light pollution intensity, we divided the lit pixels into three levels according to the DN value (Table 1). Pixels with values between 5.5 and 10 were considered to represent moderate light pollution levels because the number of pixels decreased rapidly with the increase of the DN value and the speed of the decrease slowed down significantly at a value of 10; pixels with values above 30 indicated strong light pollution as this value is generally used as a threshold to extract urban areas [35,36]. Pixels with values between 10 and 30 indicated medium levels. To evaluate how light pollution levels changed from the first to the fifth sub-period, we employed the light pollution level transfer matrix, which shows the number of pixels transferring from one level to another.

Table 1. Division of light pollution levels in China based on DN (digital number) values.

Light Pollution	DN Range
None	[0, 5.5]
Moderate	[5.5, 10]
Medium	[10, 30]
Strong	[30, 63]

3. Results

Based on WDPA, China´s nature reserves cover a total area of 1.59 million km^2.The percentage of protected areas of the whole area of the Qinghai-Tibet is the largest (41.29%), while for East China, the lowest percentage was found (3.20%) (Table 2). Northeast China, Inner Mongolia region, and Southwest China have similar values of nearly 10%. In the Qinghai-Tibet, the size of the protected areas was highest, followed by the Inner Mongolia and Northwest China. In contrast, in South China, East China, Central China, and North China, the protected areas are relatively small.

Table 2. Basic data of the protected areas in different regions of China.

Region	Total Size of Region (km^2)	Ratio of Protected Area (%)	Mean Size of Protected Area (km^2)
China	9,469,276	16.87	888.35
Northeast China	785,308	9.89	352.31
North China	525,541	4.96	185.09
East China	207,173	3.20	161.04
Central China	869,649	7.61	174.81
South China	566,367	6.58	108.24
Inner Mongolia	1,145,347	10.56	1868.48
Northwest China	2,292,999	14.34	1802.45
Southwest China	1,121,045	11.91	258.93
Qinghai-Tibet	1,918,959	41.29	12,872.03

3.1. Scope Change of Light Pollution

Overall, for China, the protected area subject to light pollution increased about 1.79 times from 1992 to 2012, while the POLPs in all regions more than doubled from 1992 to 2012 (Table 3). In general, the eastern developed regions (North China, East China, and South China) showed wider scopes of light pollution and higher absolute increases of POLP than the other regions. The absolute increase of East China was the highest and its POLP exceeded 40% in the fifth sub-period. In the Qinghai-Tibet region, although the absolute change was the smallest (0.076%), the POLP increased by 19 times during the period.

Table 3. Pixels in protected areas (POLP) [a] values of different regions from the first sub-period (1992–1996) to the fifth sub-period (2009–2012).

Region	POLP of the First Sub-Period (%)	POLP of the Fifth Sub-Period (%)	Absolute Change [b] (%)	Relative Change [c] (%)
China	1.513	4.225	2.712	179.247
Northeast China	7.104	16.226	9.122	128.407
North China	18.110	36.415	18.305	101.077
East China	11.088	43.462	32.374	291.973
Central China	3.814	14.452	10.638	278.920
South China	5.854	17.546	11.692	199.727
Inner Mongolia	1.441	4.698	3.257	226.024
Northwest China	0.977	2.393	1.416	144.933
Southwest China	2.529	8.905	6.376	252.115
Qinghai-Tibet	0.004	0.080	0.076	1900.000

[a] POLP is the proportion of lit pixels in protected areas. [b] Absolute change is the value of POLP in fifth sub-period minus POLP in the first sub-period. [c] Relative change is the percentage of absolute change according for POLP in the first sub-period.

3.2. Intensity Change of Light Pollution in PAs

For PAs in all regions, the proportion of pixels increasing in brightness (DN change > 3) was significantly higher than those decreasing in brightness (DN change < −3) (Figure 3), meaning that the area where light pollution aggravated was much larger than the area where light pollution mitigated. In East China, the PAs were subject to the highest range of brightness increase, followed by the PAs in North China. In contrast, increases in brightness were relatively low in the PAs of Qinghai-Tibet, Northwest China, and Inner Mongolia. There was no pixel in the PAs of Qinghai-Tibet experiencing a decrease in brightness, while in North China, the proportion of protected area decreasing in brightness was the highest, followed by Northeast China.

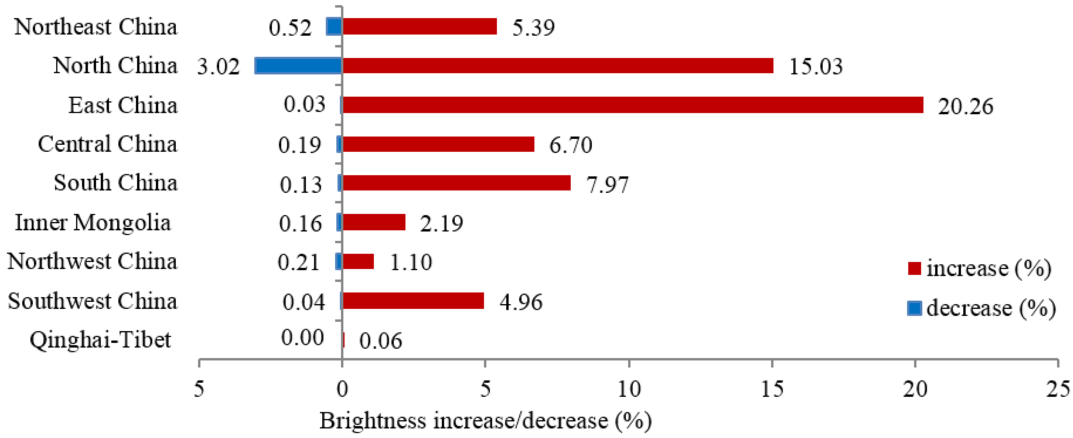

Figure 3. Percentage of protected area increasing/decreasing in brightness between the first sub-period (1992–1995) and the fifth sub-period (2009–2012). Pixels with a digital number (DN) increase above 3 increased in brightness, while those with a DN decrease above 3 decreased. When the DN change was below 3, no change occurred.

3.3. Changes of Light Pollution at Different Levels

In this section, we examined the changes of different levels of light pollution from two aspects: changes in the scope of light pollution and the inter-conversion of light pollution. For China as a whole, the scope of the PAs subject to light pollution continued to increase during the study period, with the rate increasing significantly in the second sub-period (Figure 4). In addition, the scopes of moderate, medium, and strong light pollution increased by 1.98%, 0.44%, and 0.30%, respectively. For most regions, the increase of the proportion of pixels at medium light pollution level was faster than that at strong level. Especially in East China, during the first sub-period, the proportion of the pixels at strong level was almost the same as that at moderate level and significantly higher than that at medium level. But the number of the strong increased very slightly during the study period leading to the proportion of the medium levels surpassed that of the strong levels in the fifth sub-period. However, in North China, the proportion of the strong levels increased more rapidly than that of the medium levels. Qinghai-Tibet had the lowest POLP (below 0.1%) during the entire study period. There was no pixel at the medium or strong level in the first sub-period, but medium light pollution could be observed since the second sub-period and its area continued to increase. This region was not subject to strong light pollution across the entire study period.

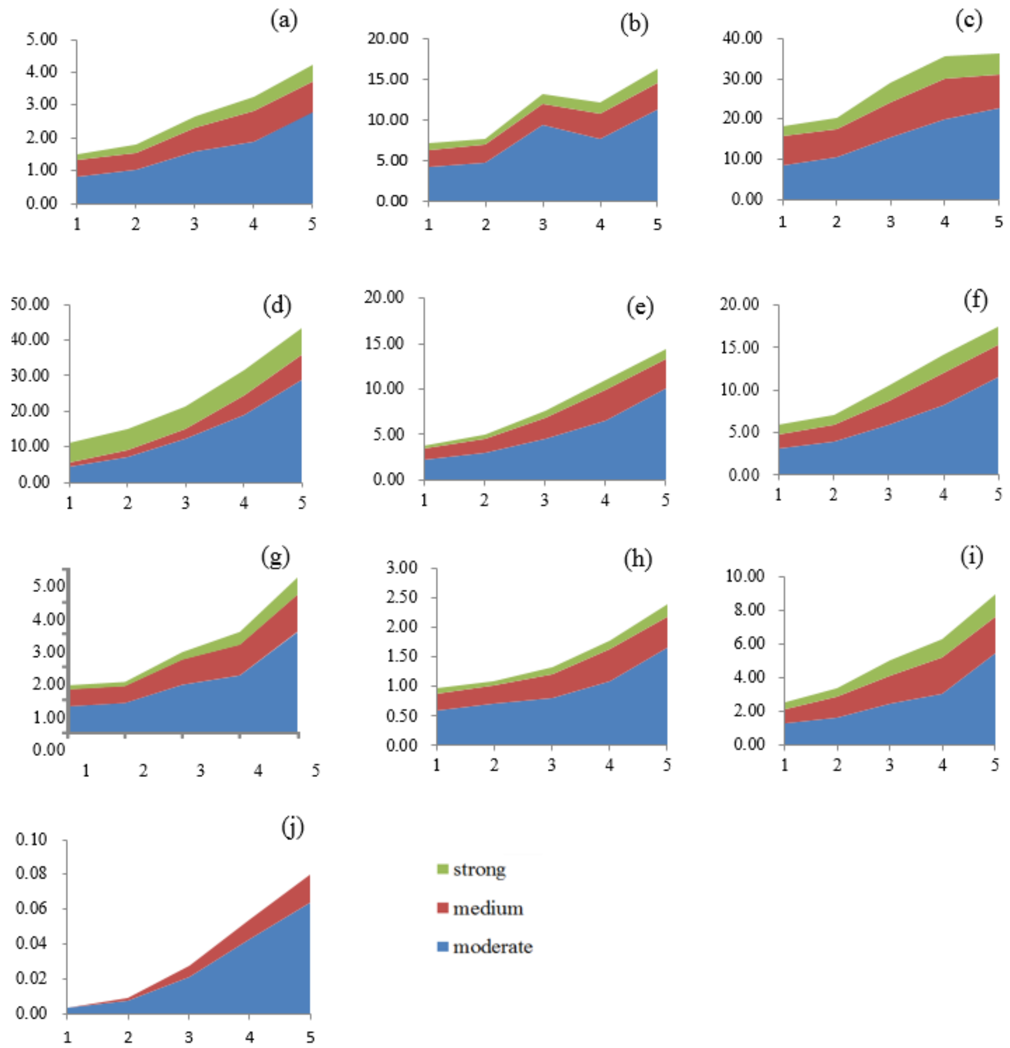

Figure 4. Changes of proportions of protected areas at different light pollution levels during the study period in (**a**) China, (**b**) Northeast China, (**c**) North China, (**d**) East China, (**e**) Central China, (**f**) South China, (**g**) Inner Mongolia, (**h**) Northwest China, (**i**) Southwest China, and (**j**) Qinghai-Tibet. The horizontal axis represents the sub-periods and the vertical axis represents the proportion of protected areas. The changes of areas in blue, red, and green represent changes of the proportions of protected areas at moderate, medium, and strong levels, respectively. Notably, ranges of vertical axis vary in different regions since the proportions of lit areas of different regions vary a lot.

Across China, a large number of unlit pixels in the first sub-period appeared, along with light pollution in the fifth sub-period, and most of them were in moderate level, some in medium level, and a very small part of them in strong level (Table 4). For pixels in moderate level, many of them aggravated to medium level and even a few of them aggravated to strong level directly. More than half of the pixels in medium level aggravated to strong level. On the contrary, the number of pixels experiencing degradation in light pollution level was relatively small. In Northeast China, the trend of aggravation in light pollution level was less than other regions. In East China, all pixels in strong level in the first sub-period were still in strong level in the fifth sub-period. In Qinghai-Tibet, a considerable number of pixels with no light pollution in the first sub-period existed with a medium degree of light pollution directly in the fifth sub-period, and most of pixels in moderate light pollution level aggravated to medium level.

Table 4. Light pollution level transfer matrix in protected areas from the first sub-period (1992–1995) to the fifth sub-period (2009–2012) *.

Region	Light Pollution	None	Moderate	Medium	Strong
China	None	1,439,495	25,445	4844	341
	Moderate	1723	4726	5501	1133
	Middle	245	916	3174	3427
	Strong	18	42	246	2841
Northeast China	None	66,220	5174	576	63
	Moderate	333	1818	1054	116
	Middle	34	203	822	588
	Strong	0	0	30	503
North China	None	17,229	3594	455	8
	Moderate	376	874	823	171
	Middle	110	239	766	757
	Strong	12	10	95	483
East China	None	4240	1296	315	24
	Moderate	5	102	131	43
	Middle	0	1	27	63
	Strong	0	0	0	354
Central China	None	58,426	4219	1012	21
	Moderate	136	407	837	129
	Middle	11	63	323	385
	Strong	0	0	6	227
South China	None	31,810	2678	491	23
	Moderate	72	377	629	99
	Middle	1	24	244	325
	Strong	0	0	1	402
Inner Mongolia	None	116,158	2132	739	115
	Moderate	251	245	332	116
	Middle	17	85	290	240
	Strong	0	0	8	156
Northwest China	None	322,029	3290	665	64
	Moderate	471	652	648	135
	Middle	72	292	309	301
	Strong	6	32	90	196
Southwest China	None	31,810	2678	491	23
	Moderate	76	248	1024	324
	Middle	0	9	393	768
	Strong	0	0	16	520
Qinghai-Tibet	None	791,573	384	100	0
	Moderate	3	3	23	0
	Middle	0	0	0	0
	Strong	0	0	0	0

* None-none represents no change, none-moderate represents a change from no to moderate light pollution, etc.

4. Discussion

Across China, the area of nature reserves in which light pollution existed increased by about 1.79 times from 1992 to 2012, which is in accordance with the increasing trend of light pollution in the world [1]. All areas subject to different light pollution levels increased during this period. Most pixels with light pollution in the first sub-period kept the pollution level or aggravated by one level, while only a few pixels had a lower level in the fifth sub-period. In the eastern developed regions (North China, East China, and South China), light pollution in PAs was more severe than in other regions and showed a more significant aggravation.

This situation was most serious in East China, with the largest increase in POLP (Table 3), maximum range of light pollution aggravation, and highest ratio of pixels in strong pollution level (Figure 3). Excluding the developed regions, light pollution was most serious in Northeast China, followed by Central China. Light pollution in PAs of Southwest China was more serious than in those of Northwest China. In Qinghai-Tibet, although the increase of light pollution was not significant compared to other regions, the range of PAs subject to light pollution increased by about 19 times from 1992 to 2012.

4.1. Factors Influencing Light Pollution in PAs

Light pollution in a PA depends on both human activities and its own characteristics. On the one hand, human activities such as urban expansion, resource exploitation, and transportation development are significant sources of light pollution. Of these, urban expansion has caused lots of natural habitat losses [37] and decreased the effectiveness of PAs [8]. We explored the effects of urban expansion on light pollution in PAs by analyzing the built-up area increase in expanded PAs, including PAs and their surrounding areas, because light pollution in PAs aroused by built-up areas around the PAs can't be neglected [1]. Since pixels within a 5-km radius of the actual lit area are potentially at risk [16], the surrounding area of a PA was represented by a 5-km buffer zone, and we examined the relationship between increase percentage of built-up areas accounting for the area of expanded PAs and the increase of POLP in different regions. The results show that the influence of built-up areas on light pollution varied across regions and was highest in North China, where the ratio between increase percentage of built-up area and increase of POLP exceeded a value of 40 (Table 5). However, increase of built-up areas still has a strong positive relationship with increase of light pollution ($R^2 > 0.95$) (Figure 5).

Table 5. Comparison between increase percentage of built-up area [a] in expanded protected areas [b] and increase of POLP [c] in different regions.

Region	Increase Percentage of Built-Up Areas in Expanded PAs	Increase of POLP	Ratio between Increase Percentage of Built-Up Area and Increase of POLP
China	0.204	2.712	13.294
Northeast China	0.583	9.122	15.647
North China	0.447	18.305	40.951
East China	2.787	32.374	11.616
Central China	0.453	10.638	23.483
South China	0.890	11.692	13.137
Inner Mongolia	0.109	3.257	29.881
Northwest China	0.048	1.416	29.500
Southwest China	0.290	6.376	21.986
Qinghai-Tibet	0.002	0.076	38.000

[a] The increase percentage of built-up area was calculated through Landsat Thematic Mapper (TM) satellite images from 1990 and 2010 at a scale of 1:100,000 and provided by the Resources and Environment Data Center of the Institute of Geographic Sciences and Natural Research, CAS. [b] Expanded protected areas include protected areas and their surrounding areas, which were represented by a 5-km buffer zone. [c] POLP is the proportion of lit pixels in protected areas, and the increase of POLP was calculated through the change between the first sub-period (1992–1995) and the fifth sub-period (2009–2012).

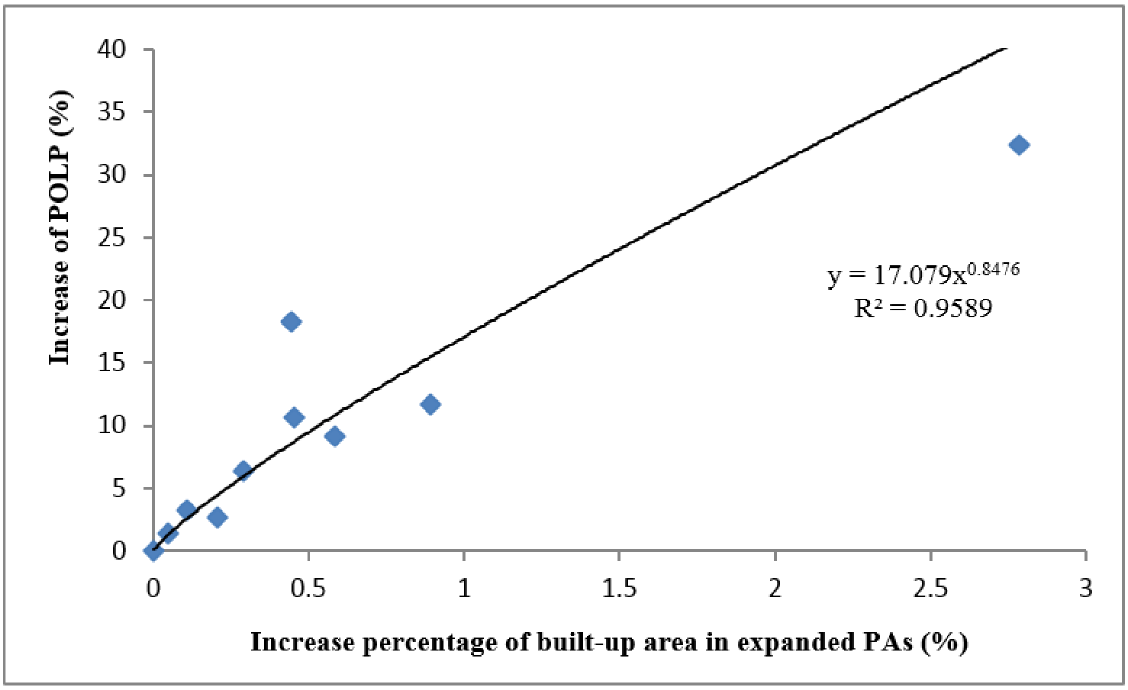

Figure 5. Relationship between increase percentage of built-up area in expanded protected areas and increase of proportion of lit areas (POLP) in different regions. Each blue square represents a region.

In addition, overexploitation of mineral resources may influence the changes in light pollution. In Northeast China, light pollution aggravation was less severe, which may be a result of the decline of the old industrial bases. For example, the Heiyupao Reserve in Daqing, Heilongjiang Province, experienced a significant light pollution mitigation (Figure 6), mainly because Daqing was one of the biggest petroleum resource-based cities but with limited resourced, the exploration began to decrease in the beginning of 21st century [38]. In North China where maximum range of decrease of light pollution in PAs took place during the study period, most mitigation took place in Shanxi (Figure 7). That may because Shanxi, as one of the key coal-producers of the country, responded actively to the "Mine Closure and Production Reduction Campaign" launched by Chinese government in the late 1990s to reform coal industry towards sustainability and many of small coal mines were closed there [39].

Transportation is also a significant light pollution source. Figure 8. shows that in Qinghai-Tibet, the night sky was significantly brighter near the railway than in other areas and a considerable number of PAs are distributed in the vicinity of railways. That demonstrates the influence of transportation on light pollution, because with low population density and undeveloped economy, other human activities are not significant in Qinghai-Tibet. Therefore, the increase of railways in Qinghai-Tibet may be the most responsible for the increase of light pollution in its PAs.

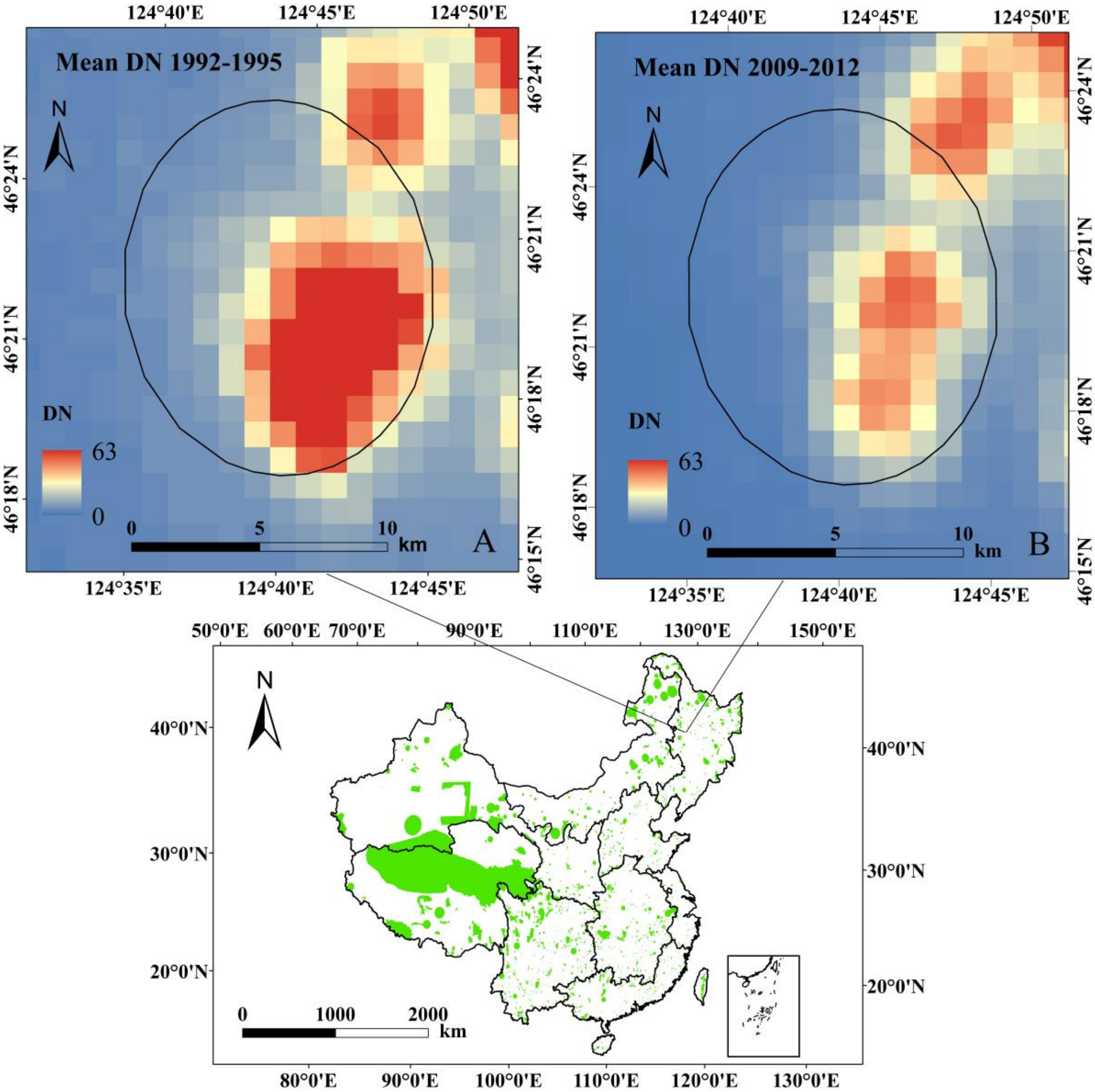

Figure 6. Nighttime lighting in Heiyupao Nature Reserve in (**A**) 1992–1995 and (**B**) 2009–2012.

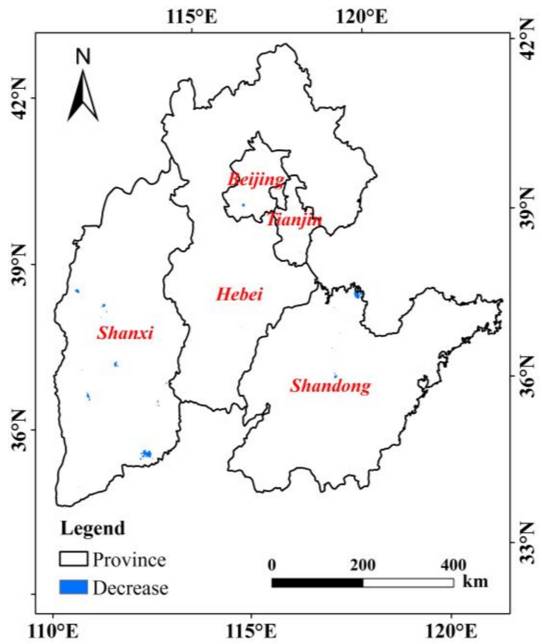

Figure 7. Distribution of pixels decreasing in light pollution in protected areas (Pas) of North China from the first sub-period (1992–1995) to the fifth sub-period (2009–2012).

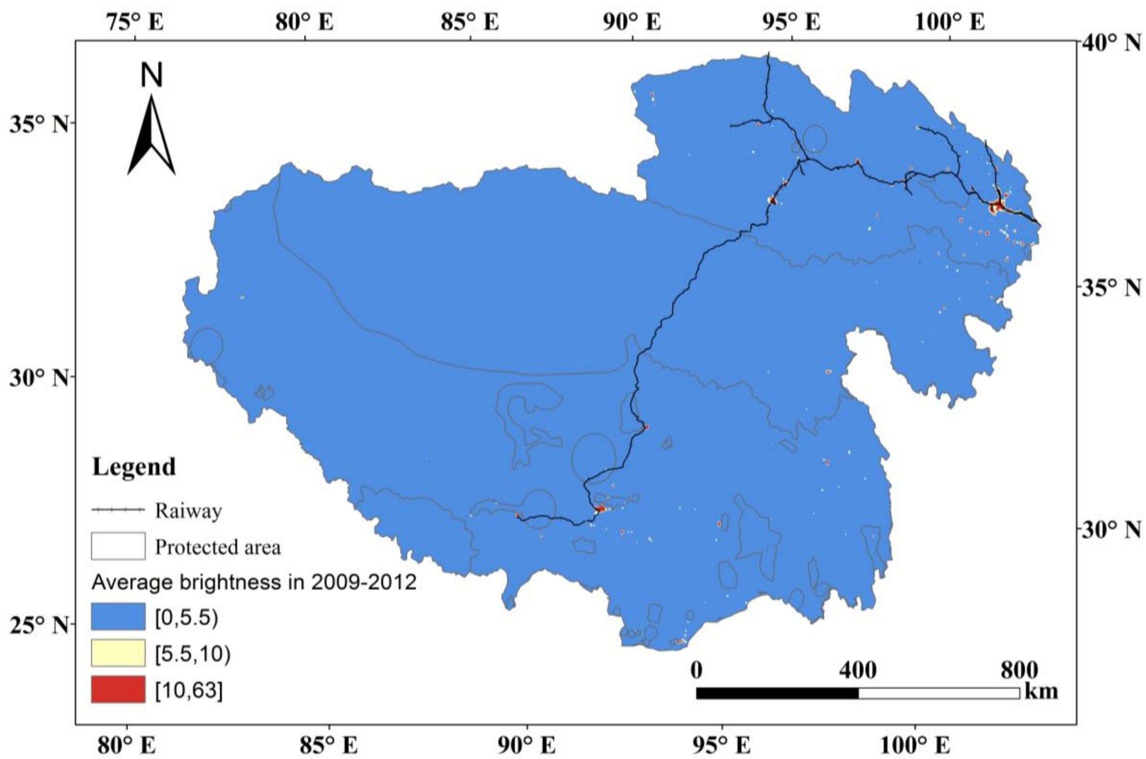

Figure 8. Nighttime lighting in the Qinghai-Tibet region in 2009–2012.

In general, density of population is a good indicator to reflect the intensity of human activities. Usually, in the region with high density of population, intensity of human activities is high, and light pollution is also serious [1]. We found out the counties to which PAs decreasing in intensity of light pollution in Shanxi belong, and calculated changes of their rural population, of which population of PAs is mainly made up, from 1992 to 2012. The results show all the counties decreased in rural population, demonstrating that another reason for the decrease in light pollution in North China is the decrease of rural population.

On the other hand, the intrinsic characteristics of a reserve, mainly its size and topography, are likely to influence the level of light pollution. Firstly, Figure 9 shows that smaller PAs tend to have a higher percentage of area with light pollution, possibly because a small PA is more likely to be illuminated by surrounding artificial light. This might partly explain the finding that light pollution in Southwest China was more serious than in Northwest China. Secondly, the extent of the influence of a light source is larger on flat ground than on hilly terrain [14]. The fact that light pollution in South China was not as severe as in East China and North China may be a result of the different terrain and geography of these regions. East China and North China are mainly flat, while South China is more mountainous.

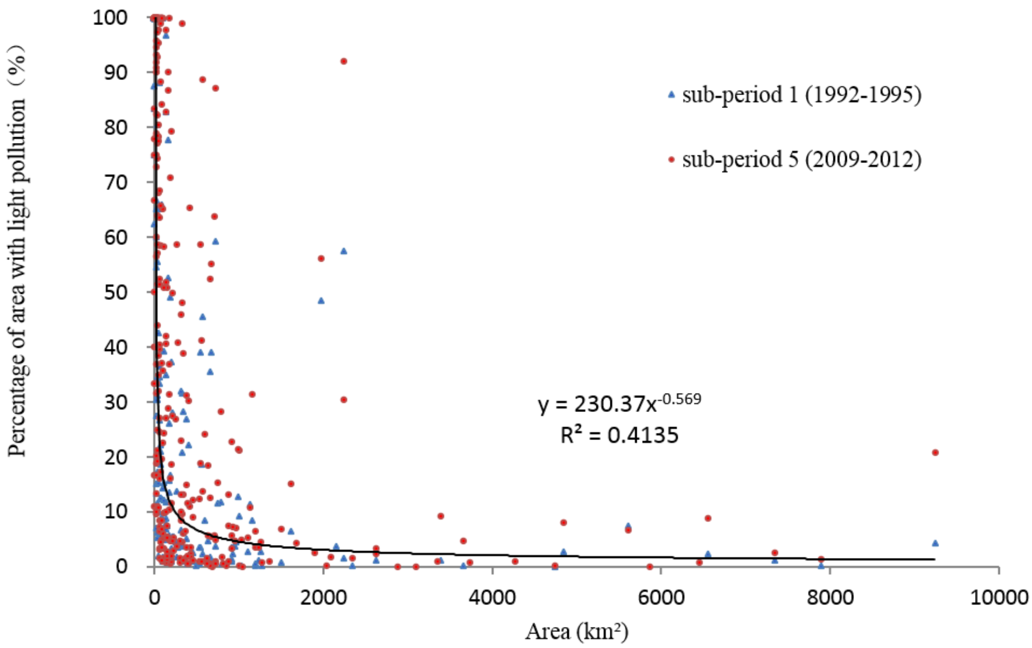

Figure 9. Scatter diagram between areas and percentages of area with light pollution. Each point represents a PA.

4.2. Limitations and Future Perspectives

This study discussed the spatial-temporal changes in light pollution in China during the period 1992–2012. Some limitations, however, remain and require further work. First, the rectification of nighttime data needs further improvement to enhance the continuity between different sensors. Second, the factors influencing light pollution in PAs are complex, and in this study we only analyzed general factors. Further studies should therefore focus on a more in-depth analysis of individual factors.

5. Conclusions

By overlaying DMSP/OLS nighttime light data and the spatial distribution of China's PAs, this paper studied how light pollution in China's PAs changed from 1992 to 2012. At the national level, first, the proportion of lit pixels in PAs increased about 1.79 times, from 1.513% during the first sub-period (1992–1995) to 4.225% during the fifth sub-period (2009–2012); second, the area of different light pollution levels all increased during this period and most pixels with light pollution in the first sub-period kept the pollution level or aggravated by one level.

In addition, the situation varied across regions. In the eastern developed regions (North China, East China, and South China), light pollution in PAs was more severe than in other regions and aggravated significantly. Of them, the situation of East China was the most serious. In PAs of this region, the proportion of lit pixels increased by about 32.4%, and all pixels at a strong light pollution level didn't improve. In PAs of Qinghai-Tibet, although the increase of light pollution was not significant compared to other regions, the range of PAs with existing light pollution increased about 19 times.

Light pollution in a PA depends on both human activities (sources of light pollution) and the PA's own characteristics (influencing the spread of light pollution). The increase of built-up areas has a strong positive relationship with the increase of light pollution, and even a small increase of the built-up area can cause a large increase in light pollution. This was the most significant in North China. Therefore, built-up areas' expansion inside and surrounding PAs should be controlled. On the other hand, PAs with smaller areas tend to have higher percentages of area with light pollution, so PAs should not be built in fragmentation.

Acknowledgments: This work was supported by the national Key Research and Development Program of China (2016YFC0502103) and the National Program on Key Basic Research Project of China (973 Program) (2015CB4527052015CB452700).

Author Contributions: Wenli Xiang and Minghong Tan designed the study. Wenli Xiang analyzed the data and wrote the paper. Minghong Tan helped in paper writing and analysis.

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

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