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Disproportioned Performances of Protected Areas in the Beijing-Tianjin-Hebei Region

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Abstract: Designing and managing protected areas (PAs) has always been value-based. While all PAs provide unique values in a region, it has not been documented if their functional contributions are proportional to their land area. A challenge also arises from the governance of PAs due to differences in supporting resources, legislations, conservation goals, and guidance. Using the Beijing-Tianjin-Hebei (BTH) region as our testbed, we designed a study to test the hypothesis that the functional contributions of 84 PAs, measured by various ecosystem service values, vulnerability and human footprint (Hf), are not proportional to land areas relative to the regional total. Disproportionate performances are partially due to the governance (i.e., national, provincial and local) and the dominant ecosystem type of each PA. We confirm our hypothesis that the functional contributions of PAs in the BTH region far exceed their total land area, with forested PAs performing better. The functional measures of PAs are highly correlated but not equally provided among PA types and under different governances. Both governance and PA type play significant roles in determining functional values and human influences, but no significant interactive influences were detected. Results from this study are updated shreds of evidence for promoting PAs as well as for establishing new PAs through the ongoing Ecological Red Lines program.

Keywords: protected areas; ecological red line; conservation objective; ecosystem services; governance; sustainability

1. Introduction

The concept of placing certain areas under protection was developed from the realization that there is unique and irreplaceable value in some landscapes [1]. The first official proposal to establish a protected area, led by Frederick Law Olmsted in 1865, argued that the Yosemite Valley and the Mariposa Big Tree Grove should be treated as parks so “the most certain value and gratification afforded by a park” could be experienced by people [2]. The proposal emphasized the importance of contact with the wilderness for human well-being, the effect of beautiful scenery on human perception, and the moral responsibility of governments to preserve regions of extraordinary natural beauty for the benefit of all people. The Organic Act of the US congress in 1916 officially established the National Park Service to “conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations”. The act was largely influenced by John Muir’s enthusiastic publications in 1913 and the persuasion of the government [3], as well as by public engagement (e.g., the establishment of the Sierra Club). This concept and associated practices have received global support from people and governments. By 2018, 8.3 million km² (21%) of global lands were under various forms of protection, reflecting a continued increasing trend [4]. In Europe, 1.34 million km² are

under PAs (>120,000) in 2018, which is ~25% of its terrestrial area [5,6]. In China, where the concept was promoted only in the late 1970s, the total proportion of protected areas (PAs) increased from 0.13% (12,700 km²) in 1978 to 14.88% (1.47 million km²) in 2017 [7,8]—a 116-fold increase over 40 years.

There are several critical principles in establishing and maintaining PAs. First, it is a value-based approach, although the values are often loosely defined, vague, or single-minded [9,10]. Early PAs (e.g., the first PA in Sierra Nevada and the first national park in Yellowstone) were established mostly because of their unique geographical features (e.g., the giant sequoia—the largest tree species on the Earth, geothermal features, etc.) and aesthetic beauty. Many global PAs were established to preserve specific features (e.g., cultural heritage, archeological sites, wildlife habitat, rich species, or sites of endangered species, etc.). Secondly, PAs are designed for current and future benefit—sustainability [11,12]. They support human well-being and livelihoods by providing various ecosystem services (ES). Third, both the public and governments are responsible for the success of PA establishment and maintenance [13]. PAs are managed by different levels of government (e.g., county, provincial, or national). Increasingly, nonprofit and for-profit organizations (e.g., the Nature Conservancy) step up to promote PAs, sometimes becoming involved in management practices [14]. Clearly, both governance and human activities affect the service values of PAs. A crucial question here is whether current PAs can effectively provide multiple services to a society [15,16] through different management [17].

Assessing and enhancing PA performances has long been a global effort [11]. Many studies have explored the provisions of ecosystem services generated by PAs [15], by arguing that their performances can be further improved [18]. A few studies also quantified performance on a regional scale [19,20]. Unfortunately, previous studies focus mostly on individual functions (e.g., species diversity), with limited efforts to address the independency of multiple values. While we do know that all PAs provide unique values, we do not have sufficient knowledge of their contributions to the overall values of a region, i.e., if these contributions are proportional to their land area. A challenge also arises from PA type and governance due to differences in supporting resources, legislations, conservation goals, guidance (i.e., missions), etc.

This study was motivated by the need to address these pressing issues, i.e., how key values of PAs under different governances and for different types in a region may vary. The lessons will be useful for revising the action plans of current PAs, as well as for designing future PAs [21]. After a quantitative analysis of the geographical structure of PAs, we calculate multiple value attributes. We use the Beijing-Tianjin-Hebei region (BTH) as our study site to address the aforementioned issues, with a central focus on the ecosystem values of PAs under different governances, with hope that the lessons learned can be used to improve future conservation network design in the BTH region. Specifically, we aim to (1) quantify the compositional and functional differences of PAs in the BTH region by governance and PA type, (2) examine whether the ecosystem services provided by PAs are proportional to their land areas, and (3) identify whether the functional values of PAs are equally provided under different governances and by PA type. The BTH region is one of the most populated areas in China (it includes China's capital—Beijing), with PAs that are assumed to provide water and soil retention [22]. We designed our study to answer the following questions: what conservation values are provided by PAs? Are PAs representative of BTH landscapes in supporting conservation values? How do their values vary by governance and PA type? We hypothesize that the functional contributions, measured by various ecosystem services (ESs), vulnerability and human footprint (Hf), are not proportional to land areas relative to the region's total. The disproportionate performances are partially due to the governance (i.e., national, provincial and local) and the dominant ecosystem type of each PA [23].

2. Materials and Methods

2.1. Study Area

The BTH region is located in the transitional zone between the Inner Mongolia Plateau and the North China Plain (Figure 1). The northwest is dominated by several mountains, which transition to plains in the southeast. Four ecological zones fall within the BTH region [24]: typical grasslands in the central and eastern Inner Mongolia Plateau, the Yanshan-Taihangshan mountain deciduous broad-leaved forest zone, urban agglomeration and sub-urban agricultural zone, and the agricultural zone.

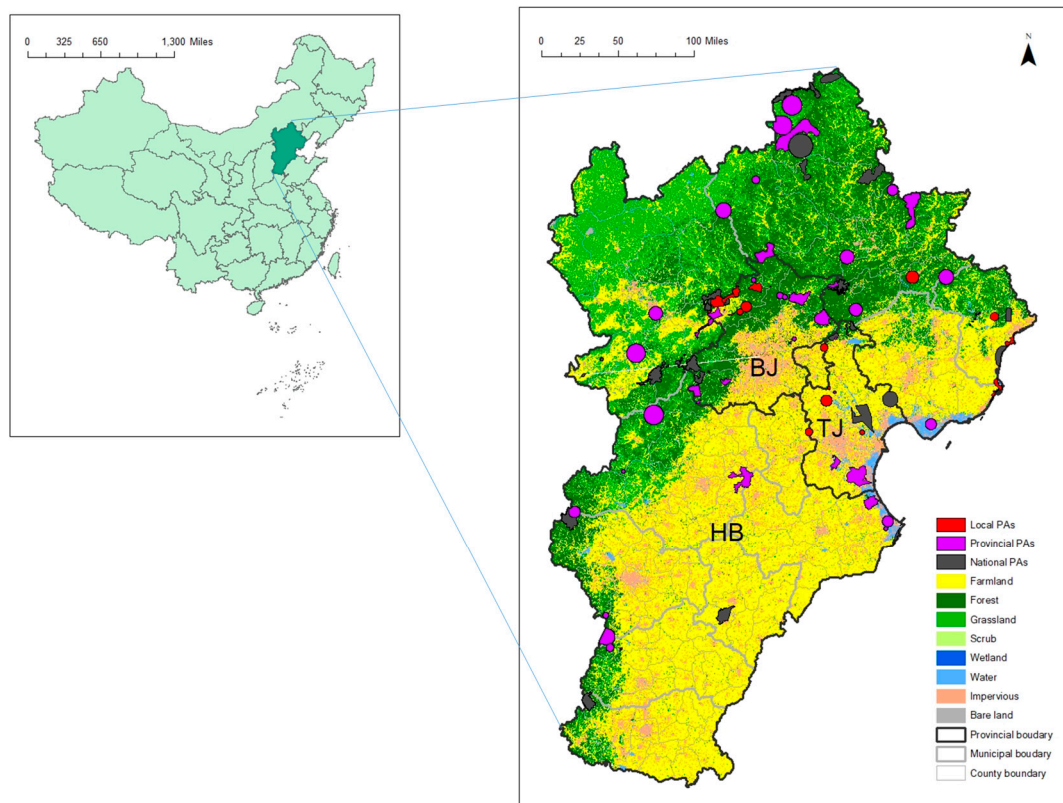


Figure 1. Location of Beijing-Tianjin-Hebei (BTH) region in eastern China and the spatial distributions of protected areas (PAs) overlaid on current land cover map. The PAs marked in black, purple and red are administrated by the national, provincial, and local government, respectively. BJ: Beijing. TJ: Tianjin; HB: Hebei.

2.2. PAs within BTH

Geographical location and associated information about PAs were extracted from the protected area database of National Forestry Administration [25], with additional statistics drawn from Wu et al. (2011) [9] and IUCN [26]. Within the database, some PAs were not described by their boundaries but by their total area and coordinates; we use symbols (Circles) to present these sites (Figure 1). These PAs are mostly distributed in mountainous areas in the northwest parts of the region. The 84 PAs include all the nature reserves and some of the forest parks, wetland parks and geological parks in BTH, covering 10,413 km² (4.83% of BTH) (Table 1). These PAs are administrated by national (23), provincial (42), and local (19) governments. The mean (STD) of national PAs (93 ± 129 km²) is larger than provincial PAs (74 ± 123 km²) and local PAs (31 ± 41 km²). In terms of dominant cover type within each PA, forest PAs are the most common, in 44 PAs, which cover 5989 km² (57.5% of the total). On average, grassland-dominated PAs are the largest (205 km²), compared to forest (75 km²) and others (40–52 km²). Among the three provinces, 45 PAs are in Tianjin, 28 in Beijing and 11 in Hebei (Table 1).

Table 1. Major statistics of the protected areas (PAs) by governance, dominant land cover type, and administrative jurisdiction in the Beijing-Tianjin-Hebei (BTH) region of China.

Categories		No	Size (km ²)				Total (km ²)	Portion (%)
			Mean	Min	Max	STD		
Governance	National	23	93	3	506	129	3625	1.68
	Provincial	42	74	1	507	123	5768	2.67
	Local	19	31	1	140	41	1020	0.47
Dominant Cover	Forest	44	75	4	507	130	5896	2.73
	Grassland	4	205	145	322	67	859	0.40
	Water	13	52	1	348	101	2671	1.24
	Others	23	40	10	344	95	987	0.46
Administrative Authority	Beijing	28	34	1	236	65	1864	0.86
	Tianjin	45	47	6	344	123	1233	0.57
	Hebei	11	104	4	507	128	7316	3.39
Overall		84	65	1	507	119	10,413	4.83

2.3. Validation of Performances

Six indices as conservation objectives for regional importance were chosen. To justify the most appropriate conservation objectives, we first collected all relevant indices after reviewing over a hundred studies in BTH [27–30]. These indices were further evaluated and limited to six based upon typical indicator selection criteria of specificity, portable, measurability, sensitivity [31–33]. We calculated six indices as conservation objectives (COs). Four are ecosystem services: climate regulation (Cr), water retention (Wr), soil retention (Sr), and wind prevention (Wp). Two are for ecosystem vulnerability: soil erosion (Se) and desertification (De). We also calculated the human footprint index (Hf), which reflects the level of human activities as a stressor.

Water retention (Wr) volume is calculated using the water balance equation in InVEST [34,35]; the amount of soil retention (Sr) and the sensitivity index of soil erosion (Se) are calculated by the RUSLE model [36,37]. Rainfall data is extracted from the 1-km monthly and annual precipitation data of the Human Geosystem Sedisystem Sedodatabase (<http://www.data.ac.cn/>). The yield ratio (K) comes from the literature [36,38]. Vegetation cover is quantified from the 1-km NDVI Monthly Synthesis (MOD09A1) of NASA's EOS data center for 2000–2009 (<https://modis.gsfc.nasa.gov/>). The vegetation type is from the 1-km global land cover of the University of Maryland (<http://glcfapp.glcfc.umd.edu:8080/esdi/index.jsp>). Soil type and soil texture are derived from the 1:1 million soil space (94,000 plots) attribute data of the second National Land Survey by the Institute of Soil Science, CAS. The 90-m Digital Terrain Elevation Model (DEM) is from the International Scientific Data Mirror Network (<http://www.gscloud.cn>) of the Computer Network Information Center, CAS. The precipitation, runoff ratio, soil, DEM and MODIS data for 2000–2009 are scaled to 1-km as required input variables in our calculations.

The climate regulation service index (Cr) is extracted from the 1-km dataset for China, which was developed by the Institute of Geosciences and Resources, CAS, in 2015 [39]. The wind prevention (Wp) and Desertification (De) in 2015 are from the 250-m grid data of the Institute of Environmental Science Planning and Design [28]. The 2009 human ecological footprint index (Hf) is 1-km grid of Venter, which is based on population density, land cover type, accessibility, and electricity infrastructure to model human impacts [40]. All the data are synchronized to 1-km grid spatial data for BTH within the ArcGIS platform.

2.4. Statistical Analysis

To answer the above questions and achieve our study objectives, we performed statistical analyses to test two specific hypotheses: (1) there exist significant differences in the functional contributions of PAs, which are highly dependent on a PA's governance and type; and (2) the ratio between conservation

objective values of the PAs (CO_{PA}) and the total CO values of the BTH region (CO_{total}) is disproportional to their land areas (A_{PA}), wherein $CO_{PA}:CO_{total} \neq A_{PA}:A_{total}$. Additionally, these disproportions vary by PA governance and type. Two-way analysis of variances (ANOVA) is performed to quantify the independent and interactive influences of governances (three levels) and types (forest and non-forest) on each CO measure. When interactive influences are not significant ($p > 0.05$), we proceed with the independent effects of governance and PA type for each objective value. As local management practices are based on multiple functions instead of individual ones, the CO values at county and planning unit (PU) levels may correlate with each other because of similar governance and PA type. There are 175 counties and 53,661 PUs within BTH; to provide useful evidence for future management, we calculated the correlations of CO values at PU level (i.e., 2×2 km).

3. Results

3.1. Landscape Composition of the PAs and BTH

Farmlands account for 45.5% of the BTH region, followed by forests (22.6%), grasslands (18.1%), and urban build-ups (10.0%) (Figure 2). In comparison, PAs have a composition of 49.7% forests, 19.1% farmlands, and 18.1% grasslands. The proportion of water bodies within the PAs is much higher (5.8%) than that of the region (1.8%). Not surprisingly, the ratio of urban build-ups within the PAs (4.7%) is less than half of the regional value. It is worth noting that the portion of wetlands within the PAs is small (0.2%) but still several orders of the magnitude higher than that in the BTH (Figure 2). The landscape composition of PAs varies substantially by governance. National and local PAs have higher proportions of forests than provincial PAs, whereas water and grasslands are more common in provincial PAs than in national and local PAs. Relatively high proportions of farmland and built-up areas are also apparent in local PAs.

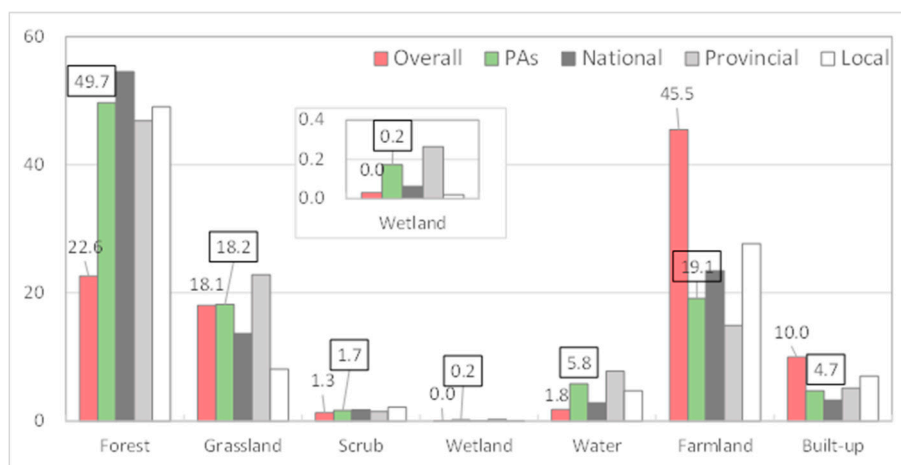


Figure 2. Landscape compositions (%) of protected areas (PAs) in the BTH region by governance.

3.2. Conservation Objective Value of the PAs and BTH

The average unit value of five COs in the PAs is higher than those of BTH; the De value is the same as for BTH region. As expected, the human footprint (Hf) of the PAs (14.1) is lower than that of BTH (18.4) (Table 2). Overall, PAs provide the highest relative soil retention (Sr) at 7.75% and the lowest relative contribution to water retention (Wr) at 5.04%. The human footprint (Hf) of all PAs is 3.70%, which is far below that of the 4.83% of BTH land dedicated to PAs (Table 1). When compared among governances, the CO values per unit of land area in national PAs show higher amounts than those of the region, whereas provincial and local PAs provide similar or even lower values. The Hf of local PAs (16.0), for example, is surprisingly higher than that of national and provincial PAs (13.8–14.0), as well as the regional mean. Lower CO values in provincial PAs are coupled with their overall large

sizes (Table 1), while local PAs have a substantially higher proportion of build-ups (Figure 2) and human footprint (Table 2). It is worth mentioning that Wr and Sr values per square kilometer at national and local levels are relatively higher than they are on a provincial level, while Se and De, the two vulnerability values, are higher on a provincial level than the other two levels. When PAs are divided into forest and non-forest groups, CO values (except De) are substantially higher in forest-dominated PAs, and Hf values are higher in non-forest PAs. In sum, differences in CO values and human footprint vary by governance and type; local PAs appear to be more influenced by human activities (e.g., build-ups).

Table 2. Values of six key conservation objectives and human footprint index (Hf) of the protected areas (PAs) in BTH region. The contribution of each conservation objective (CO) value is calculated as the CO per square kilometer (the measurement unit of climate regulation (Cr) is RMB, Wr is m³, and soil retention (Sr) and wind prevention (Wp) is ton; soil erosion (Se), desertification (De) and Hf are unitless; Se and De range 0–5.5 and 0–12.6, respectively; and Hf score ranges 12–96 within BTH), and its proportional contribution (%) is calculated as the CO values of the PAs to the total CO values of BTH.

	Cr	Wr	Sr	Wp	Se	De	Hf
	×10 ³ RMB (%)	m ³ (%)	t (%)	t (%)	(%)	(%)	(%)
Governance level							
National	2.0 (2.75)	751 (1.84)	104 (2.85)	0.22 (2.38)	3.4 (2.43)	3.8 (2.09)	14.0 (1.28)
Provincial	1.8 (4.05)	686 (2.68)	92 (4.02)	0.19 (3.26)	3.7 (4.14)	4.9 (4.22)	13.8 (2.01)
Local	1.7 (0.65)	753 (0.52)	114 (0.88)	0.13 (0.39)	3.3 (0.65)	3.8 (0.56)	16.0 (0.41)
PA Type							
Forest	2.4 (5.35)	773 (3.09)	144 (6.43)	0.22 (3.96)	4.1 (4.75)	4.2 (3.71)	12.3 (1.83)
Non-forest	1.2 (2.09)	639 (1.96)	37 (1.32)	0.15 (2.07)	2.8 (2.47)	4.6 (3.16)	16.4 (1.87)
Overall							
PAs	1.9 (7.44)	715 (5.04)	98 (7.75)	0.19 (6.04)	3.6 (7.22)	4.4 (6.88)	14.1 (3.70)
BTH	1.2 (100)	686 (100)	61 (100)	0.15 (100)	2.4 (100)	4.4 (100)	18.4 (100)

Our linear ANOVA indicates there is no significant interactive effect ($p < 0.05$) of governance (G) and PA type (E) on the six CO values and the human footprint (Table 3). The ANOVA models explained small amounts of variation, with R² varying from 0.112 for De to 0.338 for Sr. The eta squared values further indicated that PA type is the primary independent variable in comparisons with governance and the interactive effect (E*G). For Cr, Sr and Se, PA type is responsible for 23.5%, 33.1% and 21.5% of the total variance, respectively. For human footprint, both G and E are significant independent influences. For the main effect, the p -value for Wp is <0.05 (Table 3), with the partial least square indicating that 11% of the variation is from PA type and 8% from governance. For De, the type is only significant (~11%) for provincial and local PAs (Table 4). As for Hf, both governance and type show significance; PA type contributes 31.8% of the variation, compared with 14.2% for governance. For eight significant contributions (bolded data in Table 3), there is a significant difference in Cr, Wr, Sr, Wp, and Se between forest and non-forest PAs with an overall variation of 654 RMB, 103 m³, 62 t, 0.052 t, and 0.788, respectively (Table 4). Whereas for Wp, there are significant differences between national and local PAs, with an average difference of 0.057 t, and for De between provincial and local PAs with a difference of 0.736.

Table 3. Statistics of the two-way ANOVA on CO values per unit land area with three levels of governance and two levels of PA type ($n = 84$). “E”: dominant ecosystem type (forest and non-forest). “G”: Governance (national, provincial and local). “E*G”: Interactive effect of E and G.

COs measure	Adjusted R ²	Term	F	p-Value	Partial Eta Squared
Climate regulation (Cr)	0.243	E	24.01	0.000	0.235
		G	2.560	0.084	0.062
		E*G	0.304	0.738	0.008
Water retention (Wr)	0.204	E	19.94	0.000	0.204
		G	0.573	0.566	0.014
		E*G	0.245	0.783	0.006
Soil retention (Sr)	0.338	E	38.53	0.000	0.331
		G	1.684	0.192	0.041
		E*G	0.219	0.749	0.007
Wind prevention (Wp)	0.130	E	9.675	0.002	0.110
		G	3.483	0.035	0.082
		E*G	0.633	0.534	0.016
Soil erosion (Se)	0.241	E	21.31	0.000	0.215
		G	2.705	0.073	0.065
		E*G	2.101	0.129	0.051
Desertification (De)	0.112	E	0.260	0.614	0.003
		G	4.727	0.012	0.108
		E*G	3.109	0.050	0.074
Human footprint (Hf)	0.330	E	36.38	0.000	0.318
		G	6.454	0.003	0.142
		E*G	0.765	0.469	0.019

Table 4. Statistical tests of conservation objective (CO) differences (t -test) when governance or type has a significant independent influence on each CO value at $p < 0.05$ (shown in Table 3). “F-NF”: test between forest and non-forest PAs. “N-L”: test between national and local PAs; “P-L” test between provincial-local PAs. “MD”: mean difference.

COs Measure	Pairs	MD	p-Value
Climate regulation (Cr)	F-NF (E)	654	0.000
Water retention (Wr)	F-NF (E)	103	0.000
Soil retention (Sr)	F-NF (E)	62	0.000
Wind prevention (Wp)	F-NF (E)	0.052	0.002
	N-L (G)	0.057	0.041
Soil erosion (Se)	F-NF (E)	0.788	0.000
Desertification (De)	P-L (G)	0.736	0.015
Human footprint (Hf)	F-NF (E)	−5.243	0.000
	P-L (G)	−5.229	0.019
	N-L (G)	−5.810	0.002

3.3. Functional and Structural Contributions of PAs

Among the 23 national PAs, 12 are classified as forest (F-N) and 11 as non-forest (NF-N). For provincial PAs, 20 are forest (F-P) and 22 are non-forest (NF-P). Local PAs include 12 forest (F-L) and 7 non-forest (NF-L). The ratios of CO values from the PAs to those of regional means (i.e., $CO_{PA}:CO_{total}$) are higher than the ratios of land area (i.e., $A_{PA}:A_{total}$). Although there exist exceptions and variations by governance and PA type, our hypothesis is accepted for all seven measures of PA functions (Figure 3). The majority of forest PAs (in green) had higher functional contributions than their land portions, with many showing near a 2:1 ratio (e.g., Cr, Sr and Se) (Figure 3a,c,d). For De and Hf,

the functional contributions of forest PAs are about 1–2 times of their area contributions (Figure 3e,f). For W_r , all forest PAs show near equal functional contributions (Figure 3b). The only PA showing a low ratio of W_r and S_r is a Xiaoshan volcanic geological heritage provincial protected area. For non-forest PAs, there appear to be no clear-cut conclusions. Most ratios for C_r and S_r are lower than their area proportion (Figure 3a,c), and their ratios for W_r and H_f are similar to the area ratios (Figure 3b,d,f). However, the D_e ratios are 1–2 times their area ratios (Figure 3e).

Governance also plays an important role in the relationships between $CO_{PA}:CO_{total}$ and $A_{PA}:A_{total}$. National forest PAs (green triangle) have ratios above the 1:1 line, with a few exceptions such as Baixian Mountain national PA and Horn ditch provincial PA. For S_r , most ratios below the 1:1 line are provincial non-forest PAs (red circles). For D_e of the non-forest PAs (red), provincial PAs (circle) are above the 1:2 line, while all national PAs (triangular) are below the 1:1 line. Local PAs show similar ratios, albeit the variations are much higher.

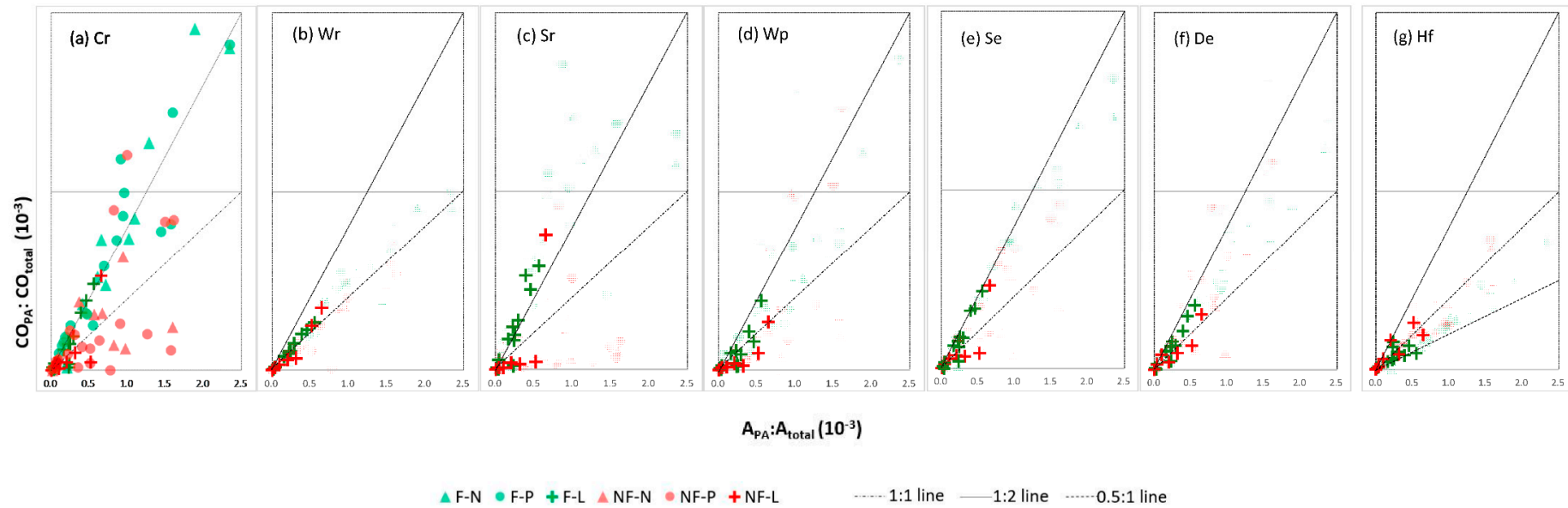


Figure 3. Relationships between $CO_{PA}:CO_{total}$ and $A_{PA}:A_{total}$ for the CO measures for six groups of PAs in the BTH region. The 1:1 line indicates that PAs functional contributions are equal to their land area-based contributions. The 2:1 line indicates that the functional contribution is double that of area contributions. Note that the 0.5:1 line for human footprint indicates half of humane influences.

3.4. Correlations among ES Measures

There exist variable correlations in both magnitude and direction among the seven performances of the PAs at three levels: PA, county and planning unit (PU) (Table 5). Five correlations were not significant: De vs. Sr and De vs. Hf at PA level, Hf vs. De at both PA and county level, and Sr vs. Wr at county level. Overall, the correlations at county level are higher than those at PA and PU level.

Table 5. Correlation coefficient of determination (R^2) for 21 paired relationships among six measures of conservation objectives (COs) and the human impact index (Hf) at three levels. (I) PA level (n = 84), (II) county level (n = 175), and (III) planning unit (PU) level (n = 53,661). ** indicates a significant level of 0.01, * indicates a significant level of 0.05.

	Cr	Wr	Sr	Wp	Se	De	Hi
Cr	1						
Wr	I: 0.636 ** II: -0.016 III: 0.154 **	1					
Sr	I: 0.779 ** II: 0.896 ** III: 0.640 **	I: 0.716 ** II: 0.145 III: 0.375 **	1				
Wp	I: 0.460 ** II: 0.650 ** III: 0.415 **	I: 0.233 * II: -0.198 ** III: -0.083 **	I: 0.379 ** II: 0.502 ** III: 0.334 **	1			
Se	I: 0.731 ** II: 0.780 ** III: 0.607 **	I: 0.365 ** II: -0.335 ** III: 0.048 **	I: 0.783 ** II: 0.802 ** III: 0.739 **	I: 0.524 ** II: 0.419 ** III: 0.396 **	1		
De	I: 0.024 II: 0.531 ** III: 0.410 **	I: -0.315 ** II: -0.609 ** III: -0.227 **	I: 0.076 II: 0.525 ** III: 0.436 **	I: 0.249 * II: 0.392 ** III: 0.319 **	I: 0.532 ** II: 0.902 ** III: 0.813 **	1	
Hi	I: -0.637 ** II: -0.565 ** III: -0.420 **	I: -0.336 ** II: -0.156 * III: 0.061 *	I: -0.538 ** II: -0.443 ** III: -0.400 **	I: -0.418 ** II: -0.440 ** III: -0.319 **	I: -0.577 ** II: -0.164 * III: -0.320 **	I: -0.194 II: 0.017 III: -0.162 **	1

At the three levels, four pairs of relationships present medium-high correlation ($R^2 > 0.5$): Cr-Sr, Cr-Se, Sr-Se and De-Se. Six pairs show medium correlation, with R^2 of 0.3–0.65: Cr-Wp, Cr-Hi, Sr-Hi, Sr-Wp, Wp-Se and Wp-Hf. Negative correlations are found for Cr-Wr, Wr-Wp, Wr-Se, Wr-Hi and De-Hi. Climate regulation has clear correlations with other CO measures, except a low correlation with water retention at county and PU levels, and a very low correlation with desertification at PA level. Except for soil retention, all other relationships with water retention at PU level are low or even negative. Wr-Wp and Wr-Se in PAs are positive, while for the other two levels they are negative or show a very low positive correlation. Human footprint shows low or negative relationships with other CO measures, with the highest R^2 value found for Cr.

4. Discussion

4.1. Values of Protected Areas

Designing and managing protected areas has always been value-based. This is done by reducing or restricting human activities. Through estimating ecosystem services, vulnerability and human influences of 84 PAs within the BTH region, we confirm our hypothesis that the functional contributions of the PAs in the BTH region far exceed their total land area (Figure 3). Some ecosystem services are double of their area portion, though with exceptions. These estimates provide us promising evidence supporting the success of PAs in BTH, which were developed mostly within the past three decades [24], albeit the first PA in China was established in 1956.

Regardless of the overall disproportionate performance of PAs, there exist substantial differences among the seven measures we examined, as well as the PA types. Compared to the 4.83% area contribution, all six indicators of the PAs provide 5%–7.8% contribution, while the human impact of the PAs (3.7%) is lower than that of the region. Most PAs worldwide were initially designed to protect biological diversity amid an increasing recognition of their other functions such as enhancing ecosystem services and regulating regional climate [41,42]. Within the BTH, 72 of the 84 PAs were originally designed to conserve species. Through testing a hypothesis on the area-function ratio, we demonstrate that PAs provide more value than other land cover types within the BTH region. The average values of all four ecosystem services are higher for PAs compared with the regional means. This is coupled with lower human influences within the PAs (Table 2). However, we found that non-forest PAs did not always provide expected values when compared with regional means (Figure 3). This is especially true for their low contributions to climate regulation, soil regulation, and wind prevention. A possible reason is that BTH is in a temperate deciduous forest zone [18]. Restored non-forest PAs from croplands within the BTH would function differently than forests.

Finally, it is worth reiterating the correlations among functional measures of PAs because ecosystem services, vulnerability and human influences are not provided equally by each PA. Four pairs of metrics (Sr-Se, Cr-Sr, Cr-Se and De-Se) are highly correlated. While the high correlation of Sr-Se is likely because they are predicted with the same model, Cr's correlations with all other indicators (e.g., Wp and De) are reasonable because both wind erosion and desertification are related to climatic changes. In sum, PAs provide multiple functions in addition to the preservation of biodiversity. Integrating ecosystem functions and ecosystem services for assessing existing PAs and establishing new PAs is necessary in order to promote collaborative conservations and enhance the efficiency of conservation and management.

4.2. The Role of Governance and Type

Our second hypothesis is also accepted, i.e., both governance and PA type play significant roles in determining functional values and human influences. However, our initial premise was that governance might dominate over PA type in explaining variations because national PAs receive more resources from the government and have more restricted rules for human activities. However, this is proven untrue by our results. For Cr, Sr and Hf, PA type explains 20–33% of the total variation, whereas governance explains 8%–11%. The more important role of PA type compared with governance, meanwhile, emphasizes that the initial decision in establishing PA type is very crucial for its subsequent functions. Another surprise in this study is the insignificant interactions between governance and PA type. Forest PAs are one of the most protected ecosystems on a global level because of their great contributions to climate mitigation [43,44]. Our results confirm these continued efforts on the part of forest PAs within the BTH region.

The proportion of forests and water bodies in the PAs within the BTH is more than twice the regional average, while the proportion of grassland is similar to the regional mean. Plausibly, forest PAs accounts for the largest proportion, and water bodies account for the largest proportion in provincial protection spaces. Water bodies, meanwhile, are less sensitive to the area of protection than the others. In general, the trend among forest groups is obvious compared with non-forest groups, and forests are more concentrated even among human influence factors. The points in the forest group are basically sensitive to area increases, and certain characteristics, especially soil preservation and climate regulation, increase even more than twice the proportion of the increase in area. Nevertheless, this trend varies with different objectives, especially within the vulnerable group.

The governance, nonetheless, plays a significant role in Wp and De, especially on a local level. The overall function of national PAs is higher than those of provincial and local PAs (Table 2). The primary reason for this may be higher supporting resources and stricter regulations, such as access to and activities allowed inside the parks. On the other hand, the Wr and Sr of local PAs are higher than those of provincial and national PAs due to a stronger interest in reducing wind and soil erosions

through management. This suggests that management practices (and regulations) applied to national PAs can potentially be applied to provincial and local PAs. Meanwhile, local PAs are often closer to human populations or accessed more by residents. This means that they provide spaces and other functions to people that may not be replaceable by provincial and national PAs [45]. The overall higher services of W_r and S_r from local PAs are direct evidence for promoting more local PAs for human well-being. More research is needed to integrate social and economic elements on smaller scales [46].

Localized protected areas are closer to human settlements and have higher human impact. Their contribution to key ecosystem functions on a regional scale is generally lower, but this does not mean it is not important [47]. In holistic national or regional spatial planning, these localized protected areas scattered around human settlements not only provide diversified value to meet human needs but also contribute a continuous flow and network for wholesome ecosystem functions in the region, such as the ecosystem services and functions in this study. In large-scale spatial planning, it is necessary to recognize their roles and combine their contribution. For these close-knit protected areas, more research is needed to confirm their significance, as well as modes and patterns that are more meaningful on local, regional and national levels. Future studies should further identify and optimize the design of such spaces in the study area.

4.3. Implications for Future Research

This study sheds light on the importance of existing PAs in supporting the six conservation objects in BTH and achieving multifunctionality of PAs, which is increasingly important in China [48]. Effective planning and governance of PAs are much more complicated than we revealed in this paper, and we would suggest that future research addresses the following issues further. First, biodiversity is the primary goal of most current PAs, and more studies are needed to understand whether biodiversity has been achieved and what the relationships between biodiversity and other ecological objectives are. Second, aesthetic and recreational values have not been identified as important in many studies of BTH but have been highlighted in regional studies from other countries [49,50]. Third, conflicts between PAs and other land uses are pressing issues to be addressed. Conservation areas in BTH have been and will be in strong competition with other land uses such as urbanization. Maintaining the quantity and the quality of PAs must be placed in the context of other land uses and developments.

Achieving multiple conservation objectives including biodiversity, ecosystem functions and services is expected when designing and developing alternative management plans for PAs. Here, we provide updated evidence for PAs' performances within BTH. Lessons learned from this study will be useful for governments who are gearing up to increase the number of PA (i.e., from current 18% to 20% in the future). The evolving philosophy exists to enhance cumulative values through integrating existing and future PAs [27]; for example, the ongoing Ecological Red Lines project in China calls for multi-objective, systematic ecological conservation planning [51]. With rapid changes to the global climate and escalating human activities, many unprecedented processes were not foreseen by pioneer conservationists and policymakers when managing and designing PAs [52]. As global ecosystem degradations continue [53–55], public support for promoting PAs and adopting new conservation strategies is mounting. Pressing issues include addressing the conflicts between PAs and other land uses, increasing the quantity and quality of PAs, sustaining ecosystem services, and offsetting the effects of ecosystem degradation [56]. Our findings shed a bright light on these issues, at least for PAs within the BTH region.

5. Conclusions

Through quantifying the performances of protected areas (PAs) in the BTH region, we confirmed the effectiveness of PAs that provide overall high ecosystem service values, low vulnerability and reduced human footprint. These functional measures are not proportional to their land areas relative to the regional total. The majority of forest PAs had higher functional contributions than their land portions, with many showing near a 2:1 ratio. Disproportionate performances are found to vary by

governance (i.e., national, provincial and local) and the dominant ecosystem type of PAs. These PAs provide the highest relative soil retention (Sr) at 7.75% and the lowest relative contribution to water retention (Wr) at 5.04%, which is still higher than the 4.83% of land areas dedicated to PAs. Meanwhile, the human footprint of all PAs is 3.70%. Surprisingly, we found governance and type of PA determined PA performances independently (versus their interactive effects), with national forested PAs performing the best. This study provides updated evidence supporting the concept of and continued efforts in promoting PAs. Results from this study can be useful for ongoing efforts in increasing the number, size and quality of protected areas within the BTH region, as well as for developing sustainable PAs elsewhere, achieving multiple conservation objectives through the engagement of all stakeholders.

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