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Changes in area and number of nature reserves in China

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Abstract: *Nature reserves (NR) are the cornerstone of biodiversity conservation. Over the past 60 years, the rapid expansion of NRs in China, one of the world's megadiverse countries, has played a critical role in slowing biodiversity loss. We examined the changes in the number and area of China's NRs from 1956 to 2014 and analyzed the effect of economic development on the expansion of China's NRs from 2005 to 2014 with linear models. Despite a continuing increase in the number of NRs, the total area of China's NRs decreased by 3% from 2007 to 2014. This loss resulted from downsizing and degazettement of existing NRs and a slowdown in the establishment of new ones. Nature reserves in regions with rapid economic development exhibited a greater decrease in area, suggesting that downsizing and degazettement of NRs are closely related to the intensifying competition between economic growth and conservation. For example, boundary adjustments to national NRs, the most strictly protected NRs, along the coast of China's Yellow Sea, a global biodiversity hotspot with a fast-growing economy, resulted in the loss of one-third of the total area. One of the most important ecosystems in these NRs, tidal wetlands, decreased by 27.8% because of boundary adjustments and by 25.2% because of land reclamation. Our results suggest conservation achievement, in terms of both area and quality, are declining at least in some regions in the Chinese NR estate. Although the designation of protected areas that are primarily managed for sustainable use has increased rapidly in recent years in China, we propose that NRs with biodiversity conservation as their main function should not be replaced or weakened.*

Keywords: boundary adjustment, conservation outcome, degazettement, downsizing, protected area, tidal wetlands, Yellow Sea

Cambios en la Superficie y el Número de Reservas Naturales en China

Resumen: *Las reservas naturales (RN) son la piedra angular de la conservación de la biodiversidad. Durante los últimos 60 años, la rápida expansión de las RN en China, uno de los países megadiversos, ha jugado un papel crítico en la reducción de la pérdida de biodiversidad. Examinamos los cambios en el número y superficie de las RN en China de 1956 a 2014 y analizamos el efecto del desarrollo económico en la expansión de las RN en China de 2005 a 2014 mediante modelos lineales. A pesar del incremento continuo en el número de RN, la superficie total de RN en China decreció en 3% de 2007 a 2014. Esta pérdida resultó de la reducción y cambio de registro de RN existentes y una desaceleración en el establecimiento de RN nuevas. Las reservas naturales en regiones con desarrollo económico rápido presentaron una mayor disminución en la superficie, lo que sugiere que la reducción y cambio de registro de RN están relacionados cercanamente con la intensificación de la competencia entre crecimiento económico y conservación. Por ejemplo, ajustes*

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en los límites de RN nacionales, las RN más estrictamente protegidas, a lo largo de la costa del Mar Amarillo, un sitio de importancia para la biodiversidad global con una economía en rápido crecimiento, resultó en la pérdida de un tercio de la superficie total. Uno de los ecosistemas más importantes en estas RN, humedales mareales, decreció en 27.8% debido a ajustes en los límites y en 25.2% debido a la reclamación de tierras. Nuestros resultados sugieren que los logros de conservación, en términos tanto de área como de calidad, están declinando en las RN de China. Aunque la designación de áreas protegidas administradas primariamente para un uso sustentable ha incrementado rápidamente en años recientes en China, proponemos que las RN cuya principal función es la conservación de la biodiversidad no deben ser reemplazadas o debilitadas.

Palabras Clave: ajuste de límites, área protegida, cambio de registro, humedales mareales, Mar Amarillo, reducción, resultado de la conservación

摘要: *自然保护区是生物多样性保护的基石。在过去的 60 年间, 作为全球生物多样性最丰富国家之一的中国, 自然保护区发展迅速, 为减缓全球生物多样性丧失发挥了关键作用。本文分析了 1956-2014 年间中国自然保护区数量和面积的变化, 并用线性模型分析了经济发展对 2005-2014 年间自然保护区发展的影响。尽管中国的自然保护区从建立之初数量一直在增加, 但总面积在 2007-2014 年间减少了 3%。这一减少是由于一些自然保护区面积缩小或被撤销而新建自然保护区的增速放缓所造成的。经济增长较快地区的自然保护区面积减少幅度较大, 这说明自然保护区的缩小或被撤销与经济发展和自然保护之间的冲突加剧密切相关。例如, 在中国黄海海岸这一全球生物多样性热点和经济快速增长的区域, 国家级自然保护区 (受最严格保护的自然保护区) 由于边界调整导致总面积减少了三分之一; 受边界调整和滩涂围垦的影响, 自然保护区内的滩涂湿地(具有重要保护价值的生态系统类型)面积分别减少了 27.8% 和 25.2%。本研究结果表明, 无论从面积还是从质量方面衡量, 中国自然保护区的保护功能至少在局部地区可能有所下降。近年来, 偏重于资源可持续利用功能的保护地在中国发展迅速, 但这不能取代或削弱以生物多样性保护为主要功能的自然保护区。*

关键词: 边界调整, 保护成效, 面积缩小, 撤销, 自然保护地, 潮汐湿地, 黄海

Introduction

Designation of protected areas (PAs) is a key measure for safeguarding species and ecosystems globally (Watson et al. 2014). At the end of 2014, China, one of the world's megadiverse countries, had established 2,729 nature reserves (NRs), the most strictly protected type of PA. These NRs encompass 147 million ha and cover 14.8% of China's land area (MEP 2015). China's NRs have played a critical role in biodiversity conservation. For example, the threatened giant panda (*Ailuropoda melanoleuca*) and Crested Ibis (*Nipponia nippon*) have been protected in NRs, and their populations have gradually recovered from the verge of extinction (MEP 2015). Given China's huge human population and rapid economic growth, the expansion of the NRs is a remarkable achievement and an important effort toward achieving the UN's Sustainable Development Goals and the Aichi Biodiversity Targets (ABTs) for conservation (CBD 2010; UN-DESA 2015).

Although the functions of NRs are well established (Watson et al. 2014), tension between economic growth and conservation is a long-standing and globally pervasive issue. Over the past century, many NRs have been subject to downgrading, downsizing, or degazettement (PADDD, PA downgrading, downsizing, and degazettement; Mascia & Pailler 2011) as a result of the growing human population and intensifying competition for land (Mascia & Pailler 2011; Mascia et al. 2014). Since the late 1970s, China has implemented a policy of reform to promote economic growth. With an annual economic growth rate averaging 10% over the past few decades, China has become the second largest economy in the world (Miller-Rushing et al. 2017). During this period, human activities have increased pressure on NRs in China (Liu et al. 2001, 2003; Chen 2016). For example, although exploitation of natural resources is prohibited in NRs (State Council of PRC 2005), it nevertheless occurs in many sites; some NRs have been degazetted to make way for construction projects (Ma 2016). Increasing numbers of China's NRs have undergone boundary adjustments in recent years (Xie et al. 2012; Chen 2016; Ma 2016) (Supporting Information), but it remains unclear whether these boundary adjustments have increased positive conservation outcomes or simply made space for economic growth thus impairing the conservation function of the NRs.

Nature reserve boundaries are usually conceptualized as fixed in perpetuity to protect the biodiversity within, yet environmental changes can reshape the spatial distribution of species and ecosystems (Hickling et al. 2006; Pecl et al. 2017), and some existing NRs are poorly placed with regard to conservation value (Fuller et al. 2010; Watson et al. 2014). As a consequence, the strategic adjustment of the boundaries of existing NRs to replace underperforming parts coupled with the designation of new NRs to fill conservation gaps could be important for increasing positive conservation outcomes (Hannah et al. 2007; Fuller et al. 2010). Economic incentives, however, can strongly affect NR management (Mascia & Pailler 2011; Xie et al. 2012; Visconti et al. 2015), and some boundary adjustments may have been made to create space for development rather than reflecting changed or better-understood conservation priorities.

The rapid development of China's NR system is well documented (e.g., Liu et al. 2003; Xu et al. 2017; Zhang et al. 2017), yet there remains no formal assessment of PADDD in China. We examined changes in the number and area of China's NRs over the past 60 years, explicitly accounting for newly established NRs and those that have undergone boundary adjustment or full or partial degazettement. We assessed the impacts of land-use transformation and boundary adjustments on NRs along the coast of the Yellow Sea, a global biodiversity hotspot subject to huge economic pressure (MacKinnon et al. 2012; Murray et al. 2014; Melville et al. 2016). Finally, we considered the causes of PADDD in China and make suggestions for increasing positive conservation outcomes.

Methods

Data on China's NRs were obtained from information officially published by the Ministry of Environmental Protection (MEP), which was the authority for NR management in the central government. China's NRs are classified into local (provincial and county) and national NRs. Local NRs can be recommended for promotion to national NRs (NNRs) by local governments subject to approval by the central government. The NNRs have the highest conservation priority and are given the strictest protection (State Council of PRC 2005). We analyzed the number and area changes of NRs (total and national NRs) since the 1950s, when the first NR was established in China.

Detailed information on all the boundary adjustments to NNRs are made public. Boundary adjustments to local NRs, however, are seldom announced or detailed. To determine the number and area changes for all of the NRs, we compared the checklists of NRs from 2005 to 2014. This enabled us to calculate the number and area of newly established, boundary-adjusted, and degazetted NRs and to determine area changes of NRs subject to boundary adjustments. For NNRs, we further analyzed change in area of the 3 functional zones: core area, buffer zone, and transition area. Protection strength decreases from the core area to the transition area. The core is strictly protected, and sustainable use is permitted in the transition area. Data on boundary adjustments to NNRs included only adjustments approved by the central government (State Council or the MEP) (Supporting Information).

Linear models were used to test the effect of economic development on the change in area of NRs in China from 2005 to 2014. The increase of gross domestic product per person (GDP), which is significantly related to human population density (Pearson $r = 0.68$, $p < 0.001$) was collected from the statistical yearbook for each administrative region (provincial level, $n = 31$) and was used as an indicator of regional economic development. The area of the NRs as a percentage of the total land area in the administrative region and the regional location (inland or coast) were also included in the models as independent variables. Generalized linear models (with a binomial distribution and logit link function) were used to analyze the effects of NNR size (area, logarithmically transformed), location (inland or coast), year of establishment, and ecosystem type (forest, grassland [including wilderness], inland wetland, or coast and sea) of the NNRs on their boundary adjustment (adjusted or not adjusted).

Complementing the national analysis, we conducted a regional study along the Yellow Sea coast, the region supporting the fastest-growing economy in China (MacKinnon et al. 2012), to detect the magnitude of land-use change and boundary adjustments on coastal NNRs. The tidal wetlands of the Yellow Sea have extremely high conservation value because they support numerous waterbirds and aquatic organisms as well as provide an ecological barrier that protects the densely populated coastal area against extreme weather events (MacKinnon et al. 2012; Murray et al. 2014). A total of 14 NNRs have been designated along the Yellow Sea since 1980 (Supporting Information). The Yellow and Yangtze Rivers transport huge amounts of sediment to the Yellow Sea, resulting in seaward expansion of the tidal wetlands. As a consequence, adjustments to NR boundaries so as to exclude the inland drylands and to add newly formed tidal wetlands have been commonly practiced to improve conservation. However, rapid economic development requires substantial land resources, which has led to land reclamation (land claim) on a large scale. Intertidal areas and shallow seas have been converted into dry land for industrial and aquacultural development (MacKinnon et al. 2012; Murray et al. 2014). This has put great pressure on biodiversity in the area.

Because the area of tidal wetlands is an effective indicator of conservation achievements in coastal regions (Murray et al. 2014), we used the change in area of tidal wetlands within the NNRs over time as an indicator of change in conservation achievement. An increase in area suggests improving conservation, and a decrease in area suggests a failure to improve conservation. To detect the change in area of tidal wetlands, we used all TM and ETM+ images from 1984 to 2015 in the Google Earth Engine Cloud Platform; more specifically, we used the surface reflectance data set (11,264 images [http://ledaps.nascom.nasa.gov/]). We extracted the lowest tidelines with the waterline mapping algorithm (Chen et al. 2016; Supporting Information). One cloud-free Landsat image was selected in each year to delineate artificial shorelines along the coasts through visual interpretation. We digitized the boundaries of the 14 NNRs along the Yellow Sea coast when they were designated and updated these to track boundary adjustments, calculating any change in area over time from

1985 to 2015. We analyzed changes in 3 major land-cover types—reclaimed regions (inside artificial shorelines), tidal wetlands (between artificial shorelines and the lowest tidelines), and open ocean (outside the lowest tidelines)—in each NNR and along the Yellow Sea over time with ArcGIS 10.1. Linear models were used to detect the effect of boundary adjustments on the change in area of tidal wetlands. The models also included the following independent variables: boundary adjustment (yes or no), area of tidal wetlands in the NNR when designated (logarithmically transformed), and year of designation.

The second-order bias-corrected Akaike's information criterion (AICc) was used to select the most parsimonious model from those models with ΔAICc <2 (Burnham & Anderson 2002). Data were analyzed with R (Version 3.3.2), and results are reported as means and SD.

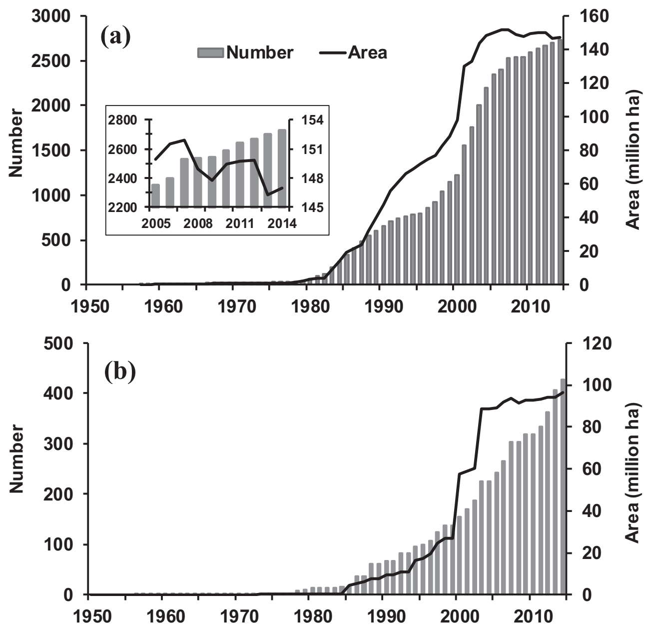

Figure 1. Number and total area of all China's (a) nature reserves and (b) national nature reserves (the most strictly protected nature reserves) from 1956 to 2014. Insert shows changes in China's nature reserves from 2005 to 2014.

Results

Change in Number and Area of China's Nature Reserves

The number and area of China's NRs increased slowly following the establishment of the first NR in 1956 until the late 1970s, by which time fewer than 50 NRs had been established. Both the number and area of NRs then increased rapidly from the 1980s; over 2,600 NRs (over 95% of the total) had been established by 2014. The fastest growth of NRs occurred from the late 1990s to the early 2000s; over 1,800 NRs (66% of the total number and 46% of the total area) were established from 1996 to 2005. Subsequently, establishment of new NRs slowed (Supporting Information). The total area of NRs peaked in 2007 at 152 million ha. Since then, although the total number of NRs increased by 198 from 2007 to 2014, the total area decreased by 4.9 million ha (Fig. 1a).

There were 428 NNRs in 2014 (15.7% of the total NRs), covering a total of 96.5 million ha (i.e., approximately 10% of China's land area). Both the number and area of NNRs have increased over the past 2 decades, but the rate of increase in area has become much slower than that of number of NNRs (Fig. 1b) because relatively few new NNRs have been established.

A total of 403 NRs were degazetted from 2005 to 2014, resulting in a loss of 4 million ha of PA (Fig. 2). All the degazetted sites were local NRs. Fifty NNRs had their boundaries adjusted, including 7 with 2 adjustments during the period (Supporting Information). Nearly half (49.1%, 28 of 57) of those boundary adjustments resulted in a reduction in total area, 22.8% (13 of 57) resulted in no change in area, and 28.1% (16 of 57) resulted in an increase in area. Taken together, all boundary adjustments of NNRs caused a net loss of 2.8 million ha of PA, which is 15.1% of the area of adjusted NNRs and 2.9% of all of the NNRs in China. The total core area shrank by 22.3% as a result of boundary adjustments. The buffer zone and the transition area shrank by 10.3% and 8.7%, respectively (Supporting Information).

Results of the linear model indicated that change in area of NRs was significantly related to regional economic development: the greater the increase in GDP, the greater the decrease in NR area. Furthermore, NRs in coastal regions and in regions where NR comprised a higher percentage of the regional land area also showed a greater decrease in area (Fig. 3 & Supporting Information). Generalized linear models indicated that NNRs with larger area and that were established earlier and were located in coastal regions were more likely to undergo boundary adjustment than small NNRs or those established later or located inland. The different ecosystem types exhibited similar probabilities of boundary adjustment (Fig. 4 & Supporting Information).

Boundary Adjustments to NNRs in the Yellow Sea

Along the Yellow Sea coast, 8 NNRs underwent boundary adjustments; 3 were adjusted twice (Supporting Information). A total of 2.01 million ha, including 199,000 ha of tidal wetlands, 1.17 million ha of open ocean, and 674,000 ha of reclaimed area, was included in the NNRs when they were designated. The total area of coastal NNRs reached its maximum in 2006 (2.00 million ha) and then decreased as a result of boundary adjustments. The total area of the NNRs in 2015 (1.32 million

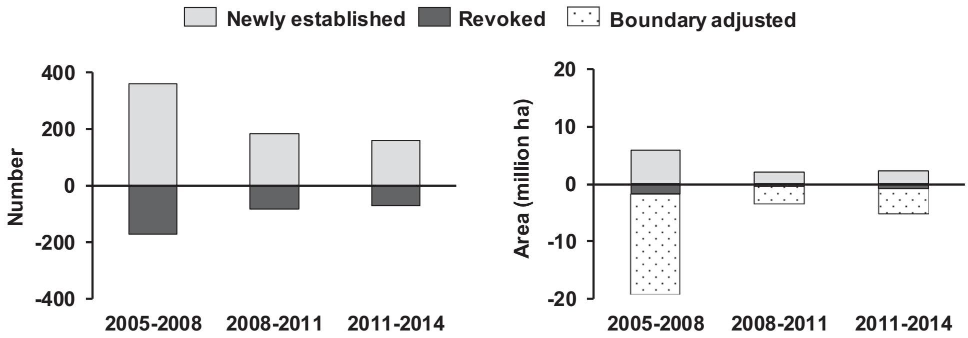

Figure 2. Number and area of the newly established, degazetted, and boundary-adjusted nature reserves in China from 2005 to 2014.

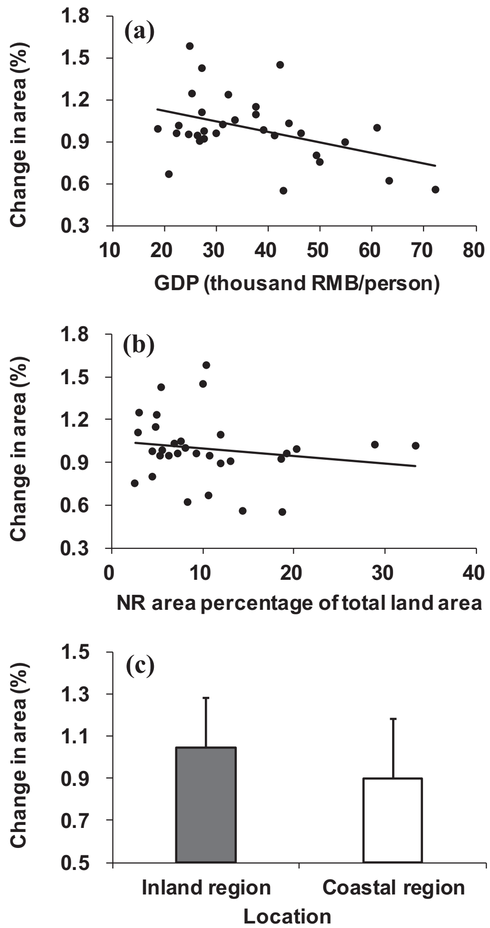

Figure 3. From 2005 to 2014, relationship between change in area of nature reserves in each administrative region and (a) increase in the gross domestic product (GDP), (b) nature reserve (NR) area percent relative to the total land area, and (c) location of the administrative region (inland or coastal).

ha) was only 66.1% of that in 2006 (Supporting Information). Boundary adjustments excluded a total of 453,000 ha of wetlands from NNRs that had been subject to land reclamation and added 13,800 ha of tidal wetlands to NNRs. However, boundary adjustment also removed 51,200 ha of tidal wetlands from the NNRs, and these regions excluded from NNRs were subject to development projects such as the construction of ports, industrial zones, and infrastructure. Overall, the area of NNRs decreased by 49.6% for the reclaimed regions, 48.2% for tidal wetlands, and 21.4% for open ocean from the time of designation of the NNRs to 2015 (Fig. 5).

National NRs with boundary adjustment exhibited significantly greater loss of tidal wetlands (annual average loss 3.1% [SD 2.5], $n = 8$) than those without boundary adjustment (annual average increase 1.9% [SD 4.1], $n = 6$; $p = 0.01$) (Fig. 6 & Supporting Information). From the time of designation of NNRs until 2015, sites without boundary adjustments had a net loss of 14.5% of total tidal wetland area due to land reclamation. In contrast, tidal wetland area in the NNRs with boundary adjustments had a net loss of 54.6%, including 27.8% due to boundary adjustments and 26.8% directly due to land reclamation. Meanwhile, the area of reclaimed region decreased by 55.1% in the NNRs with boundary adjustments but increased by 17.1% in the NNRs without boundary adjustments (Fig. 5). Moreover, NNRs with a large tidal wetland area were likely to be subjected to more tidal wetland loss than those with a small tidal wetland area ($p = 0.03$) (Fig. 6 & Supporting Information).

Under the dual influence of land reclamation and boundary adjustments, tidal wetlands in NNRs had a net loss of 31.8% from 2000 to 2015, which was close to the decrease of tidal wetland area outside NNRs (34.8%) in the Yellow Sea region. Consequently, the proportion of the total tidal wetland area in the Yellow Sea within NNRs remained stable from 1990 to 2015 (Supporting Information). The tidal wetland area in the NNRs represented 33.9% of the total in the Yellow Sea in 2015.

Discussion

Causes of PADDD in China

Although the total number of NRs in China has increased rapidly since the 1980s, the total area of NRs has decreased in recent years because of degazettement and

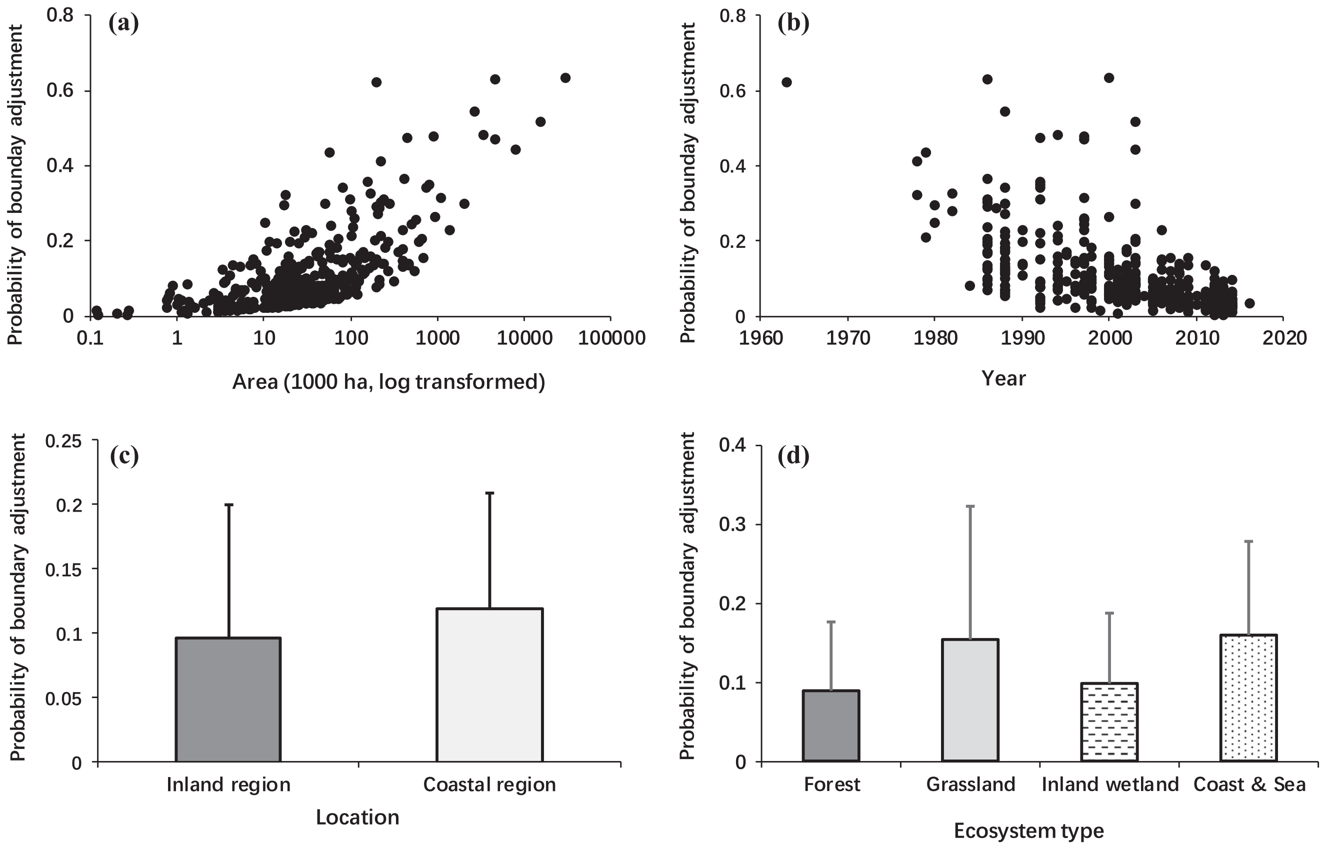

Figure 4. Probability of nature reserve (NR) boundary adjustment relative to the (a) national NR's area when established, (b) year of the national NR's establishment, (c) location of the national NR, and (d) ecosystem type of the national NR.

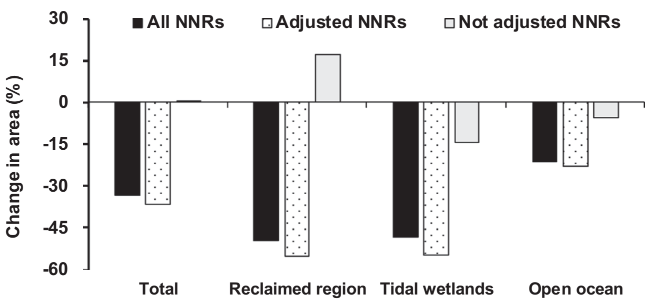

Figure 5. Change in area of total, reclaimed region, tidal wetlands, and open ocean in national nature reserves (NNRs) with boundary adjustment (adjusted) and without boundary adjustment (not adjusted) along the coast of China's Yellow Sea.

shrinkage of some established NRs. We found that NRs in regions with rapid economic development suffered a greater decrease in area, suggesting that the downsizing and degazettement of China's NRs is closely related to the intensifying conflict between economic growth and conservation, as also found in other countries and regions (Mascia & Pailler 2011; Mascia et al. 2014). In the Yellow Sea region, boundary adjustments have removed a large area of tidal wetlands with the highest conservation value from the NNRs, highlighting that boundary adjustments have failed to improve conservation and instead are likely to have resulted in an overall decrease in biodiversity conservation.

China has a bottom-up system of NR management. Establishment of new NRs and promotion of NRs from the local to national level are the responsibility of local governments. Administration, including the allocation of human resources and operating expenses of all NRs including NNRs, is also determined by local governments. This local control and lack of national planning (Liu et al. 2003; Wu et al. 2011) may explain why the NR system is unlikely to fulfill national conservation goals (Xu et al. 2017).

The management of China's NRs is currently based on weak regulation rather than strong national law (Xie et al. 2014). Because the management of NRs belongs to various administrative departments at different administrative levels, the lack of regulation increases the difficulty of management (Xie et al. 2014). We found that no NNRs have been degazetted, perhaps because the NNRs are supervised by the central government, which implements

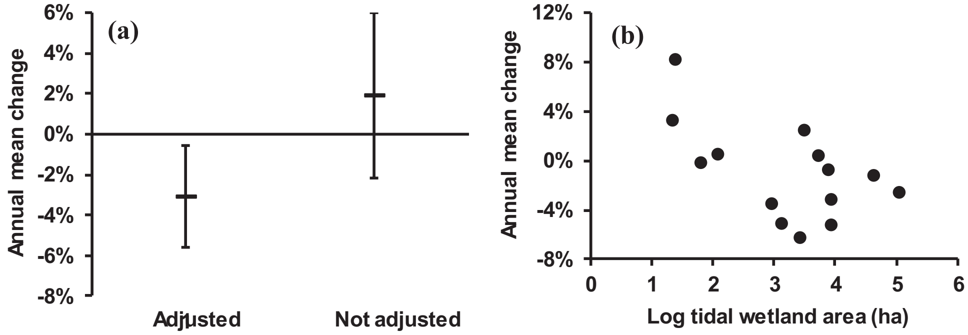

Figure 6. Annual mean change in tidal wetland area in the national nature reserves (NNRs) on the coast of the Yellow Sea relative to (a) whether the boundaries were adjusted (n = 8) or not (n = 6) (whiskers, SD) and (b) NNR tidal wetland area.

strict management of the NNRs. Some unreasonable requests by local governments for boundary adjustments to NNRs have been rejected by the central government (Ma 2016). However, local NRs are under the jurisdiction of local governments, which make boundary adjustment and even degazettement of local NRs more arbitrary. Our results indicate that over 400 local NRs were degazetted over the past few decades. Most of them were directly degazetted by local governments for the purpose of resource exploitation without implementation of any assessment procedure (Chen 2016). It is therefore unclear what conservation values has been lost. In 2017, the MEP surveyed 660 local NRs and found that natural resource exploitation occurred in every one (MEP 2017), strongly suggesting that local NRs are less effective than NNRs.

China's NRs have increased rapidly since the 1990s. This increase is closely related to the increased emphasis on conservation by the central government. China became a party to the Convention on Biological Diversity in 1993; the Regulations on the Management of Nature Reserves was promulgated in 1994; and sustainable development was adopted as a national strategy in 1995. In the late 1990s, the National Wildlife and Natural Reserve Development Program was established, putting forward the target that NRs should cover 18% of the total land area of China by 2050. The central government also created special funding mechanisms to encourage the establishment and management of NRs (Xu et al. 2012; Miller-Rushing et al. 2017). These factors led to the rapid increase in both the number and area of China's NRs.

However, some NRs established early on were not well designed; for example, densely populated villages and towns were included in NRs (Liu et al. 2001, 2003; Xu et al. 2012). Many NRs have been poorly managed. A major problem is that most land within the NRs is collectively or individually owned, which means authorities have no legal rights to manage the land, adding to the difficulty of conservation. Local people often settle in NRs and depend on its resources for their livelihood (Liu et al. 2001, 2003; Xu et al. 2012). Although sustainable use of resources inside the NRs benefits local economic development, the absence of effective management of human activities creates a conflict between conservation and economic activities, a conflict that intensifies as economic development increases (Liu et al. 2003).

The development of NRs is highly dependent on the support of local governments, their attitudes greatly affect conservation outcomes. Local governments, however, have long given priority to the promotion of vigorous economic growth, which can sometimes lead to land exploitation (Ma 2016). Following rapid economic growth that began in the late 1970s, there has been an increasingly acute shortage of land suitable for development. Because of constraints on the exploitation of NRs by regulations, many local governments have changed their attitude from being enthusiastic to being unwilling to establish new NRs. Some local governments even believe existing NRs are obstacles to economic growth (Xie et al. 2012; Ma 2016).

Against this background, it is not uncommon for NRs to be downsized to facilitate exploitation when conflicts between conservation and economic growth occur (Xie et al. 2012; Chen 2016; Zhang et al. 2017). Compared with inland regions, the coastal regions support higher population densities and more rapid economic growth (Melville et al. 2016) such that coastal NRs have had intense pressure from land exploitation. We found that boundary adjustments to NNRs resulted in a net loss of 2.8 million ha of PA, which largely offsets the increase of PA due to establishment of new NRs. Our results indicate that among the 3 function zones of NNRs, core area decreased the most in area because of boundary adjustments. This could be related to the fact that core area is under the highest level of protection. Development activities in these areas are completely prohibited, whereas some activities are allowed within buffer and transition areas (State Council of PRC 2005). Reducing the core area can free up more space for development.

There has been dramatic loss and degradation of tidal wetlands in the Yellow Sea (MacKinnon et al. 2012; Murray et al. 2014, 2015). However, we have demonstrated that even within the strictly protected NNRs, downsizing (by boundary adjustment) and destruction and degradation (by land reclamation) have caused extensive loss of supposedly protected tidal wetlands in the Yellow Sea. Because biodiversity is greater in NRs than in unprotected areas, loss of tidal wetlands in NRs has greater negative effects on conservation than loss of wetlands outside NRs. An assessment of the conservation effectiveness of NNRs along China's coasts indicates that nearly half of the NNRs are in a poor condition (Zheng et al. 2012), suggesting that PADDD is not limited to the Yellow Sea coast.

The percentage of tidal wetland area protected by NNRs along the Yellow Sea coast in 2015 (>30%) was much higher than that required by ABTs (17%) by 2020 (CBD 2010). However, the fact that the percentage of tidal wetlands protected within NNRs has been maintained despite the dramatic decrease in the area of NNRs highlights that maintaining a mandatory minimum percentage as PA cannot be the only criterion used to evaluate conservation outcomes. Along the Yellow Sea coast, some sites with high conservation priority remain unprotected and are under increasing pressure from land reclamation (Melville et al. 2016). The dramatic decline of biodiversity and ecosystem services along the Yellow Sea coast (Murray et al. 2015; Studds et al. 2017) in recent years further demonstrates the inadequacies of tidal wetland conservation. Because biodiversity is unevenly distributed, a uniform criterion based on the percentage of area protected is unsuitable for distinguishing between regions that are sufficiently protected and those that need additional protection (Rodrigues et al. 2004; Pouzols et al. 2014).

We found that large NNRs decreased in area more than small NNRs nationwide and along the Yellow Sea coast. This suggests the larger NNRs, which have high opportunity costs, have more natural resource exploitation than the smaller ones (Symes et al. 2016). Because some species and ecological processes require large areas (Xie et al. 2014), a decrease in the area of large NRs in China is likely to be accompanied by a decrease in positive conservation outcomes.

In recent years, the central government in China has increasingly emphasized conservation. Since 2013, MEP required a no net loss of PA, especially core areas, when boundaries of NRs are adjusted (State Council of PRC 2013). Some applications by local governments for boundary adjustments to reduce the area of NNRs have been rejected (Zhang et al. 2017). This curbed the reduction of area caused by boundary adjustments. The loss of PA in boundary-adjusted NNRs decreased from 21.8% before 2013 to 12.8% from 2013 to 2015. Some local leaders have even been punished for illegal exploitation of NNRs (MEP 2016, 2017). There is still reason for concern, however, because many boundary adjustments to NRs have been made that replaced areas of high conservation value with areas of low conservation value to facilitate exploitation of natural resources (Chen 2016; Zhang et al. 2017). Such boundary adjustments, including direct exclusion of high-conservation-value areas or alternative protection of "land nobody wants," result in an overall decrease in positive conservation outcomes (Visconti et al. 2015).

Prospects

By 2014 China's NRs covered nearly 15% of the country's land area, and the total area of all PA types accounted for 25.5% of the land area (Zhang et al. 2017). The PA coverage in China was significantly higher than the global average (15.4%) and exceeded the ABT of 17% by 2020 (CBD 2010). However, many conservation gaps still exist. For example, a recent nationwide assessment of the effectiveness of China's NRs indicates they cannot adequately protect either biodiversity or key ecosystem services (Xu et al. 2017). Across their annual cycle, <10% of migratory birds are adequately covered by China's NRs (Runge et al. 2015), and some critical habitats for maintenance of globally threatened migratory bird populations remain unprotected (Melville et al. 2016). By 2014, moreover, China's NRs covered only 1% of the marine area (Zhang et al. 2017), which is much lower than the ABT of 10% by 2020 (CBD 2010).

Because of China's huge human population and the associated increase in exploitation of natural resources, it is unlikely that the area of China's NRs will increase substantially in the future. On the contrary, the current PADDD suggests an overall reduction in conservation. There is therefore an urgent need for effective measures to improve conservation in NRs.

First, overall planning and prioritization of NR designation are required at the national level. Establishing new NRs and promotion of NRs from local to NNRs should be based on ecological representativeness, biodiversity hotspots, and conservation priorities rather than the willingness of local governments. Second, the biodiversity status and conservation outcomes of existing NRs should be periodically assessed to provide a basis for NR management. Boundary adjustments to NRs should target increasing positive conservation outcomes. Strict procedures for the degazettement of NRs are also required. An effective classification and management system for all PA types should be established (Xia et al. 2011). Some NRs that have relatively less value for biodiversity conservation could be redesignated as another PA type that mainly targets sustainable use. Third, it is necessary to formulate an effective NR law that clarifies the duties, rights, and obligations of authorities at various administrative levels. Legislation should also endow the NR management agency with the right to manage all areas within NRs (Xie et al. 2012) and assist in preventing unreasonable administrative interference by local governments in NR management. Finally, international communication and cooperation will be helpful for sharing experiences and lessons in NR management. The challenges of PADDD are not unique to China but occur in many countries worldwide (Mascia & Pailler 2011). The root of the problem, which is resource exploitation in NRs, is similar among many NRs (Mascia & Pailler 2011; Watson et al. 2014). Sharing knowledge about conservation planning, making regulations, coordinating requirements among agencies, and encouraging public participation in conservation will help improve management of China's NRs. Solutions to the problems in China will also provide examples that will improve NR management globally (Miller-Rushing et al. 2017).

China's central government has strengthened biodiversity and ecosystem conservation in recent years to achieve the target of "eco-civilization" (CPC Central Committee and the State Council 2015). In 2015, the strategic project Delineation and Defense of Ecological Protection Red Lines was launched to integrate all the regions that provide critical ecosystem services and ecological security into a protection system with unified and strict management (He et al. 2018). The central government is also exploring a comprehensive national park system that will protect important ecosystems and wildlife as well as ensure sustainable use of natural resources (Xu et al. 2017). These efforts should improve the management of NRs. A clear understanding of the challenges faced by NRs, together with solutions to those challenges, will be crucial as this process unfolds. In recent years, other PA types with the main function of sustainable use (e.g., scenic spots, forest parks, and wetland parks) have increased rapidly in China (Zhang et al. 2017). While recognizing the importance of such public PAs, we propose that NRs with biodiversity conservation as their main function should not be replaced or weakened. Given the increasing impact of human activities on the planet, strictly protected NRs will become increasingly important for the maintenance of biodiversity and healthy ecosystems, upon which human well-being ultimately depends.

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Supporting Information

Methodological details (Appendix S1), location of NNRs along the Yellow Sea coast in China and location of the Yellow Sea in East Asia (Appendix S2), number and area of China's NRs established each year from 1956 to 2014 (Appendix S3), changes in number and area of national NRs along the Yellow Sea coast in China (Appendix S4), area of tidal wetlands in NNRs and their percentage of the total along the Yellow Sea coast in China (Appendix S5), boundary adjustments to NNRs (Appendix S6), NNRs along China's Yellow Sea coast (Appendix S7), and estimated accuracy of validating 3 land-cover types in the Yellow Sea coast (Appendix S8) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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