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Understanding and minimizing environmental impacts of the Belt and Road Initiative

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Abstract: *China's Belt and Road Initiative (BRI) sets to create connections and build infrastructure across Eurasia, Asia, and parts of the African continent in its initial phase and is the largest infrastructure project of all time. Any infrastructure project on this scale will necessarily pass through ecofragile regions and key biodiversity areas (KBAs). This creates an imperative to identify possible areas of impact and probable effects on conservation values to facilitate adaptive planning and to mitigate, minimize, or avoid impacts. Using the highest resolution route maps of the BRI available, I overlaid the proposed road and rail routes on KBAs, protected areas, and predicted biodiversity hotspots for over 4138 animal and 7371 plant species. I also assessed the relationship between the proposed route with the distribution of mines across BRI countries and the proportion of deforestation and forest near routes. Infrastructure, especially mining, was clustered near the proposed route; thus, construction and development along the route may increase the size and number of mines. Up to 15% of KBAs were within 1 km of proposed railways. Thus, planned and probable development along the routes may pose a significant risk to biodiversity, especially because the majority of KBAs are unprotected. Many biodiversity hotspots for different taxa were near the route. These hotspots varied between taxa, making systematic management and environmental impact assessments an effective strategy for at least some taxa. A combination of planning and mitigation strategies will likely be necessary to protect the most important areas for biodiversity proximal to development, especially in currently unprotected KBAs and other regions that need protection. A fuller assessment of trade-offs between conservation and other values will be necessary to make good decisions for each project and site being developed, including potentially modifying parts of the route to minimize impacts. Modification or foregoing of infrastructure may be needed if stakeholders consider the conservation costs too high.*

Keywords: biodiversity, China, deforestation, environmental impact assessment, infrastructure, sustainable

Conocimiento y Reducción de los Impactos Ambientales de la Iniciativa del Cinturón y Ruta

Resumen: *La Iniciativa del Cinturón y Ruta (BRI, en inglés) de China busca crear conexiones y construir infraestructura a lo largo de Eurasia, Asia y partes del continente africano en su fase inicial y es el proyecto infraestructural más grande de todos los tiempos. Cualquier proyecto infraestructural a esta escala pasará obligatoriamente a través de regiones con fragilidad ecológica y áreas importantes para la biodiversidad (KBA, en inglés). Esto genera una necesidad por identificar las áreas de posible impacto y los efectos probables sobre los valores de conservación para facilitar la planeación adaptativa y mitigar, reducir o evitar los impactos. Usé los mapas de ruta de la BRI con la mayor resolución disponible para sobreponer las rutas propuestas de ferrocarriles y carreteras sobre las KBA, las áreas protegidas y los puntos calientes de biodiversidad pronosticados para más de 4138 especies de animales y 7371 especies de plantas. También evalué la relación entre la ruta propuesta con la distribución de minas a lo largo de los países en la BRI y la proporción de deforestación y bosques cerca de las rutas. La infraestructura, en especial la de minas, estuvo agrupada cerca de la ruta propuesta; por lo tanto, la construcción y el desarrollo a lo largo de la ruta*

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podrían incrementar el tamaño y el número de minas. Hasta el 15% de las KBA estarían dentro de 1 km de distancia de las vías ferrocarrileras propuestas. Así, el desarrollo planeado y probable a lo largo de las rutas puede presentar un riesgo significativo para la biodiversidad, especialmente porque la mayoría de las KBA no está protegida. Muchos puntos calientes para la biodiversidad están cerca de la ruta. Estos puntos calientes variaron entre taxones, lo que hace que el manejo sistémico y las evaluaciones de impacto ambiental sean una estrategia efectiva para por lo menos algunos taxones. Una combinación de estrategias de planeación y mitigación probablemente será necesaria para proteger las áreas más importantes para la biodiversidad próximas al desarrollo, especialmente en las KBA que actualmente se encuentran sin protección y en otras regiones que requieren protección. Una evaluación más completa de compensaciones entre la conservación y otros valores será necesaria para tomar buenas decisiones para cada proyecto y sitio en desarrollo, incluyendo la potencial modificación de partes de la ruta para reducir los impactos. La modificación o renuncia a la infraestructura puede ser necesaria si los accionistas consideran que los costos de conservación son demasiado elevados.

Palabras Clave: biodiversidad, China, deforestación, evaluación de impacto ambiental, infraestructura, sustentable

摘要: *中国的 “一带一路” 倡议 (BRI) 是有史以来规模最大的基础设施项目, 其目标是在欧亚大, 亚洲和非洲大陆部分地区建立互联互通和基础设施建设。如此大规模的基础设施项目必定会经过生态脆弱区和生物多样性重要区域, 这就迫切需要确定可能对生物多样性保护价值产生影响的区域和可能产生的影响, 以便进行适应性规划, 尽量减轻、减少或者避免工程施工对生物多样性带来的不良影响。本文利用覆盖生物多样性重要区域 (KBAs) 和保护区拟建公路和铁路的 “一带一路” 高分辨率路线图, 预测沿线的生物多样性热点地区有超过 4138 种动物和 7371 植物种类。本文还评估了 “一带一路” 沿线各国拟建路线上矿山的分布和路线附近毁林和森林比例之间的关系。基础设施, 特别是采矿业, 成群分布在在拟建路线附近。因此, 沿线的建设和开发可能会增加矿山的规模和数量, 而多达 15% 的 KBAs 就位于拟建铁路 1 公里以内, 从而, 沿线规划和未来发展, 也许会给当地生物多样性造成严重的影响。拥有许多不同类群的生物多样性热点地区都在这条路线附近, 而其中还有许多 KBAs 都还未受到保护, 这些生物多样性热点在不同的类群之间存在差异, 因此, 系统的管理和对环境影响进行评估, 至少对某些类群来说是一种有效的策略 。***为了保护** *近期开发最重要的生物多样性地区, 尤其是目前未受到保护以及其他需要保护的地区, 对其采取统筹规划和缓解措施将会是必要的策略。为了对每一个正在开发的项目和地点做出正确的决策, 有必要对生物多样性保护和其他各种价值之间的权衡进行更全面的评估, 这包括需要修改部分路线以尽量减少对生物与环境的影响。如果计划中的基础设施建设会造成严重的生物多样性丧失, 那么就必须要重新考虑。*

关键词: 基础设施; 可持续发展; 中国; 环境影响评价; 森林砍伐; 生物多样性

Introduction

The Belt and Road Initiative (BRI) promises to be the largest infrastructure project in human history, valued over US$8 trillion by 2049, spanning possibly 72 countries (>7000 projects contracted in 2017) (MOFCOM 2017; Kirchherr et al. 2018). However, development necessarily entrains significant risks for biodiversity. Mechanisms of impact fall into 5 main classes: direct or resource destruction to build roads and associated infrastructure (Laurance et al. 2009; Tracy et al. 2017); raw material extraction for building roads or supplying resources for new human population centers (e.g., power supply) (Zapata & Gambatese 2005); increased access to natural resources (and wildlife) due to greater accessibility along the route (Espinosa et al. 2014); habitat fragmentation due to road construction (Hughes 2018); increased roadkill (Coffin 2007); and increased wildlife trafficking due to increased regional connectivity (Bush et al. 2014).

Thus, infrastructure expansion must be considered carefully to ensure minimal negative impacts on biodiversity (Tracy et al. 2017). Trade-offs exist between economic and ecological values. When economic gains entail significant biodiversity loss, stakeholders must consider the options and, in some cases, plan effect mitigation or alternative solutions that avoid impacts. Deliberative decision-making tools for multivariate problems are well established and can help reduce impact associated with infrastructure development (Gregory et al. 2012). The first step is to identify where these impacts may occur so that all planning options can be considered.

Impact pathways entail varied effects across scales (Table 1), and estimating the outcome of each requires approaches that account for these issues on an appropriate scale. I focused on gauging the impacts of direct destruction along the BRI planned route (first-order consequences), although areas beyond the road area itself will be effected (many in the Economic Belt surrounding the route) and vulnerable to development (second-order consequences [e.g., deforestation]) (Table 1).

Most studies on potential BRI impacts have relied on data that lack the spatial accuracy necessary to meaningfully measure impact (Kirchherr et al. 2018) and devise mitigation strategies. For example, many researchers

Table 1. Direct drivers of biodiversity loss (raw material extraction, access, road kill, fragmentation) and first- and second-order consequences of linear infrastructure development (supportive and related infrastructure [power generation, agriculture, mineral exploitation, connectivity]).

Direct driver	*Raw material extraction*	*Access*	*Roadkill*	*Fragmentation*
Loss of habitat	destruction of karst for cement	collection of NTFPS[a]	road kill of terrestrial species crossing or following route	shrinking patch sizes
Degradation of nearby forest regions	sand mining	hunting	road kill of arboreal species forced to climb down to transverse route	disrupting migratory routes
Loss of key sites for diversity or endemic species	water diversion	collection of ornamental species	attraction of predators to roadkill also killed	limit genetic connectivity
.	logging	access to formerly insulated populations		increased edge effect
				unable to maintain minimum viable population
				changes in flow regime and runoff
.	.	.	.	changes in thermal and humidity profile

Power generation	*Agriculture*	*Mineral exploitation*	*Linear connectivity*
Reservoir construction	exploitation of previously inaccessible areas	mining	wildlife trade
Increases in pollution from coal	chemical pollution	water pollution	spread of invasive species
Downstream floods	effluents into water courses	soil compaction	spread of disease
Downstream droughts	irrigation, changes in flow	landslide probability	human migration
Downstream saline incursion	changes in fire regime or vulnerability	.	.
Death of flying species from wind farms	increased erosion and soil loss	.	.
Changes in seismicity		.	.
Natural gas exploitation			

Note: Some implications fall under multiple drivers, but have only been listed under the likely primary driver.
[a]*Non-timber forest products.*

used IUCN data even though IUCN explicitly advises against generating hotspots maps from overlain species ranges (IUCN 2018) because many are based on regional or national checklists that cannot represent fine-scale biodiversity patterns. I circumvented these problems by using the most up-to-date maps of proposed routes (routes did not differ by >600 m) and carefully developed species distribution models for areas of greatest biodiversity. Thereby, I sought to determine where most biodiversity could be lost and how loss might be managed, mitigated, or avoided. Management is especially crucial in relatively undisturbed areas (e.g., northern areas relatively pristine) (Foggin 2018; Lechner et al. 2018).

Major portions of the route are funded and under construction, underlining the urgency of identifying potential impacts for which mitigation or avoidance should be planned. Development has halted along portions of the route for economic or political reasons (Dasgupta & Pasricha 2017; Associated Press 2018; VOA Learning English 2018), suggesting changes are possible. For instance, although most tropical Southeast Asian routes are not finalized, existing road routes will likely be used and expanded. New rail connections are proposed across the region (https://www.nomadicnotes.com/southeast-asia-rail-map/) that often traverse undeveloped areas or require substantial additional development to accommodate larger traffic volumes. I seek to promote discussions and enable biodiversity values to be considered in planning alongside social and economic factors.

China is using the BRI to further its global connections. Initial land and maritime routes (Fig. 1) will significantly affect regional biodiversity, as will the ports that interface between them, especially around the Yellow Sea, where there is essential breeding and stopover habitat for many

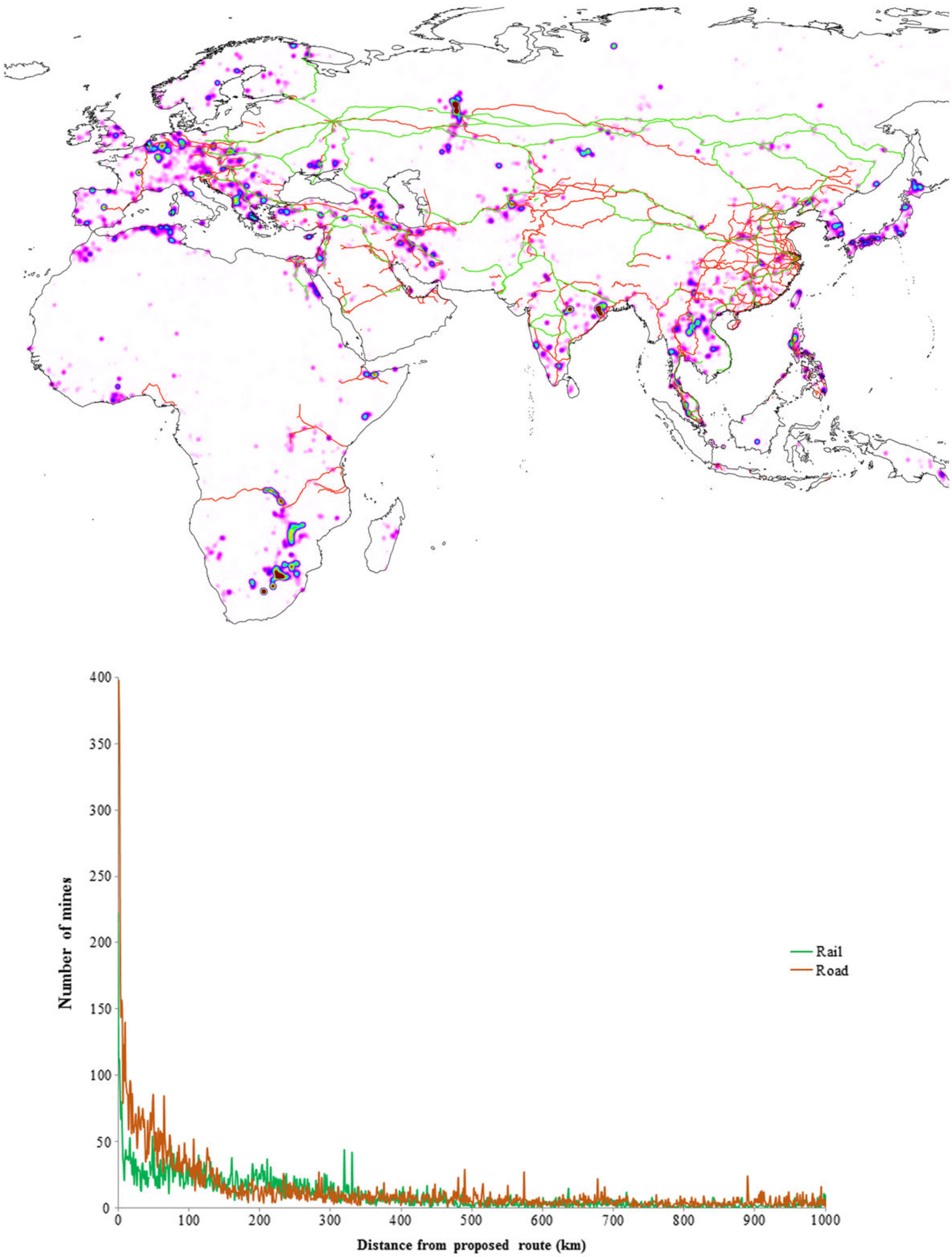

Figure 1. Areas of mining activity mapped along the Belt and Road Initiative (BRI) route: (map) mine density (purple, low; green, medium; yellow, high; orange lines, roads; green lines, rail) and (graph) distance of mines from the proposed BRI roads and rails (detailed in [a]).

birds that use the East Asian Australasian Flyway (Li et al. 2019). However, I focused on terrestrial BRI routes due to their higher certainty and ease of quantification. Mechanisms to minimize, mitigate, or avoid potential negative impacts are of immediate conservation relevance because development is underway for large parts of the BRI.

I used high-resolution GIS data to explore potential impacts of the BRI across all mapped land routes and considered how to reduce impact on key regions and scalable approaches to minimize threats to biodiversity. Although diverse consequences will stem from the development of new infrastructure, I focused on quantifying the spatial footprint of the routes on biodiversity based on mappable facets of biodiversity and other environmental correlates of biodiversity.

Methods

Reliable, accurate maps of the BRI are almost nonexistent. I collated data from 3 sources to create the most extensive and accurate compilation of roads, rail, and pipelines possible, although pipelines proved too uncertain to allow detailed analysis. Where routes were vague (i.e., northern Russia), I combined topographic and city maps (listed as BRI cities by various sources [Supporting Information]) to develop high-resolution route maps. These road- and rail-route data were intersected with protected and key biodiversity areas (KBAs). I used Hughes' (2017*a*) high-resolution models of species richness (11,509 Southeast Asian species, 6,173 orchids, 1,706 reptiles, 308 mammals, 304 amphibians, 1,820 birds, 1,198 nonvascular plants, and Old World bat models). I also examined the relationship between mine density and the BRI route (Supporting Information).

Results

Key Biodiversity and Protected Areas

The potential impact on KBAs varied; routes transected KBAs in some areas (Supporting Information). On average, 17% of KBAs were within 50 km of proposed roads and 60.6% were within 50 km of proposed rail routes (Table 2). Proposed railways were especially close to KBAs (19.9% within 7 km of a proposed rail route).

Many KBAs are unprotected; a smaller proportion of PAs were near the route than KBAs (Table 2). In contrast to KBAs, more PAs were near roads (13.5% within 50 km) than railways (6.8% near) and as large an area was protected within 30 km of roads (6.7%) as within 50 km of rails (Supporting Information). Much of Africa was particularly at risk from new routes intersecting PAs (Supporting Information).

Table 2. Number and percent area of key biodiversity areas (KBAs) and protected areas (PAs) within 5 distances from proposed road and rail routes of the Belt and Road Initiative.

Feature and distance (km)	*No. KBAs*	*KBA area (%)*	*PA area (%)*
Rail			
1	440	14.9	0.1
7	477	19.9	0.6
14	580	27.5	1.3
30	830	40.2	3.0
50	1218	60.6	6.8
Road			
1	937	0.2	0.0
7	1164	1.9	1.1
14	1458	4.0	3.0
30	1957	8.6	6.7
50	2348	17.1	13.5

Mapped Biodiversity

With the exception of bats, intersectional analysis of biodiversity hotspots and proposed routes could be conducted only for tropical Southeast Asia (Supporting Information).

With 25–49% of maximum diversity from Maxent predictions of species occurrence, 34% of important areas for mammals (least 25% of maximum richness) were within 50 km of roads in mainland Southeast Asia (Supporting Information), with 5% within 7 km of roads. More diverse areas, although smaller, had lower proportional overlap with proposed routes close to areas with up to 75% of maximum diversity. For areas with 50% of maximum diversity, mammals had the greatest vulnerability; up to 8.3% of these regions were within 50 km of proposed roads (Table 3).

Birds were most vulnerable to railways; almost 29% of regions with up to 25% of maximum diversity were within 50 km of railways, and 5% of maximum-diversity hotspots were within 7 km of railways, over double that of other taxa. For higher levels of diversity (50–74% maximum diversity), mammals were more vulnerable; 3.2% of such areas were within 50 km of railways.

At a country level (Supporting Information), Cambodia and Vietnam had the highest proportion of areas with the greatest diversity (75–100% highest mammal diversity) near proposed railways (46.9% and 25.6%, respectively). Only in Thailand and Cambodia proposed railways bisected the most diverse areas for mammals. Patterns varied dramatically across taxa. For example, for birds 16% of the most diverse areas and 38.4% of hotspots within the 50-km road buffer were in China. Malaysia had 9.4% of the most diverse bird areas and 22.6% of hotspot areas within the buffer. Vietnam had 23.8% of the most diverse areas for birds, and 51% of those areas were within the railway buffer.

For Amphibians only a small proportion of the most diverse areas fell within the road route, but of these 84.7%

Table 3. Percentage of diversity hotspots for 7 taxa within 5 different distances (1–50 km) of proposed Belt and Road Initiative rail and road routes.

		Road					*Rail*				
Taxon	*Species richness (%)*	*1*	*7*	*14*	*30*	*50*	*1*	*7*	*14*	*30*	*50*
Reptiles	25	0.5	2.7	2.6	4.2	5.6	0.6	4.2	4.5	7.9	11.8
	50	0.1	0.4	0.4	0.7	0.9	0.1	0.7	0.8	1.5	3.2
	75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Orchids	25	0.4	1.8	1.6	2.9	4.8	0.4	2.1	2.0	4.1	7.6
	50	0.1	0.3	0.1	0.1	0.3	0.1	0.2	0.2	0.2	0.3
	75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Amphibians	25	0.1	0.5	1.0	2.3	4.9	0.1	0.5	1.0	2.3	4.9
	50	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.1	0.1
	75			0.0	0.0	0.0			0.0	0.0	0.0
Birds	25	0.5	3.5	6.2	10.6	17.1	0.6	4.1	7.9	14.9	28.5
	50	0.1	0.4	0.6	0.8	1.2	0.1	0.5	0.9	1.3	2.1
	75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mammals	25	0.6	4.8	9.7	18.4	34.0	0.2	1.8	3.7	7.0	13.0
	50	0.1	0.6	1.4	3.4	8.3	0.0	0.2	0.5	1.3	3.2
	75	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.1
Pteropus*	25	0.1	1.0	1.8	3.2	5.2	0.1	1.0	1.8	3.2	5.2
	50	0.0	0.1	0.1	0.3	0.4	0.0	0.1	0.1	0.3	0.4
	75		0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0
Bats*	25	0.2	1.2	2.3	4.2	7.1	0.2	1.2	2.3	4.2	7.1
	50	0.0	0.3	0.7	1.3	2.4	0.0	0.3	0.7	1.3	2.4
	75	0.0	0.1	0.1	0.2	0.4	0.0	0.1	0.1	0.2	0.4

* *Old-World model.*

Table 4. Major options for increasing sustainability along the Belt and Road Initiative route and results of inaction.

Sustainability measures	*Results of failure to enact adequate protect*
Sustainable sourcing of energy and resources to build the BRI	continued reliance on fossil fuel and increased emissions
Offset carbon release by afforestation along the route	development of dams and other forms of supportive energy generation
Protect key sites and fragile ecosystems (i.e., KBAs within 50 km of any proposed route)	further fragmentation and forest loss along the route
Develop partnership agreements and guarantees that state key criteria should be developed to prevent unsustainable use and implement spell out (EIAs)	fragile ecosystems destroyed or exposed to unsustainable use (forest, karst)
Develop mechanisms for international oversight on EIAs	protocols to prevent the development or destruction of diverse ecosystems
Adhere to host and developer countries' relevant environmental regulations	weak or no EIAs and no mechanism for oversight
Tight screening and controls of the movement of goods (i.e., wildlife) will be needed across the route	increased trafficking of wildlife along the route

of the richest areas within the buffer area occurred in Indonesia. For railways Amphibians in Lao appeared the most vulnerable; 53.2% of the most diverse areas were within the buffer.

For reptiles 59.8% of the most diverse areas within the road buffer (17.5% of the most diverse areas) were in Thailand. In contrast, 40.4% of the most diverse areas within 50 km of railways were in India (30%, Thailand; 23%, Malaysia). For orchids in China, 90.7% of hotspots were within road buffer (50.2% of the total) and 85.5% of hotspots were near railways (11% of total).

Bats were the only group mapped for the entirety of tropical regions of the BRI; Southeast Asia appeared disproportionately vulnerable. Within road buffers, 77% of the most diverse areas were in Malaysia for bats overall (equivalent to 33% of total hotspots for bats). For rail, bats in Lao were most vulnerable; 36.9% of the most diverse areas were within the buffer.

Conservation Status

Areas with many endangered and threatened species comprised a tiny proportion of land area in Southeast Asia; 0.08% of land area had 50–75% of maximum diversity for data deficient amphibians and 0.35% of land area had this proportion of data deficient mammals. For threatened species, 9.7% of land area had 25–50% of vulnerable mammal species.

Despite their small size, a large proportion of these areas were near proposed routes (Supporting Information).

For example, 11.2% of areas with 25–50% of maximum diversity for critically endangered birds were within 50 km of railways and 6.3% were within this distance of roads; 3.8% were within 30 km.

A large proportion of data deficient mammals fell within 50 km of roads; 72.3% of areas with 75–100% of maximum data deficient species were within 50 km of a road and 14.1% were within 7 km of roads. Similarly high proportions of areas were near railways; 53.4% of the highest aggregations of data deficient mammals were within 50 km of railways.

Many with many threatened species were near parts of the proposed route, particularly in Vietnam (Supporting Information).

Deforestation

Many areas around the proposed route showed expansive forest cover and high rates of deforestation. When average forest cover and deforestation for all countries the BRI passed through were calculated, 66.4% of the area within 50 km of roads was forested, accounting for an average 21.2% of forest within countries. Overall, 1.65% of forest within buffered regions was lost from 2001 to 2017, and average forest loss for each country was 6% (Supporting Information).

For railways on average 22% of forest fell within 50 km of routes, and 24.5% of the area within this distance of railways was forested, and 5.7% of deforestation per country was within this area. On average 2.1% of the area within 50 km of railways was lost from 2001 to 2016, which was 1.41% of overall deforestation and 7.9% of deforestation in any country. Of this, 32% of deforestation within 50 km fell within 14 km of roads, despite only having 25% of the total tree coverage in the buffer. Thus, there was disproportionate deforestation within 14 km of roads. For railways 21.7% of deforestation of the buffer was within 14 km. Because only 11.7% of forest cover was within this region, there was still a disproportionate loss of forests within 14 km of railways. In total 36.4% of forest was lost from 2001 to 2016, although the level of deforestation varied greatly by region.

Pipelines, Mines, and Other Challenges

Unlike road and rail routes, proposed pipelines connected only major areas, and each pipeline route still entailed multiple, unfinalized options. Nonetheless, these routes went through numerous relatively undisturbed areas and may open these areas to development or pollution.

For much BRI-associated development mapping is not yet possible; thus, results represent a lower bound on the extent and severity of potential impacts. For all BRI countries, number and density of mines decreased sharply as distance from proposed routes increased (Fig. 1). This indicated that new roads are planned to connect areas with many mines to facilitate export. Areas along proposed routes with few mines are vulnerable to exploitation given the additional connectivity, and existing mines may be enlarged (Fig. 1).

Mappable roads along the BRI totaled 170,126 km; the rail and pipeline networks were 80,451 km and 343,677 km, respectively. If the entire road network were made with or underlain by cement (preferred road construction material in Asia [Das 2014]), roads would require 332,906 t of cement (roughly 436,107 t of limestone). Based on average dimensions, rail networks would require 28,278,527 t of cement (37,044,896 t limestone) and pipelines 157,320 t of limestone (Supporting Information).

Discussion

Few studies of the potential risks of the BRI (Tracy et al. 2017) include high-resolution spatial analyses, provide implementable suggestions for minimizing BRI impacts (Kirchherr et al. 2018), or substantively analyzed environmental implications and minimization or avoidance of impacts. Most focus on economic implications and opportunities (Pakistan [Huang et al. 2017], India [Banerjee 2016]).

Vulnerability of taxa across the BRI differed substantially (Supporting Information); thus, a range of strategies to mitigate impacts are needed. Although the level of analysis for different parts of the route varied, some key diversity hotspots were clearly at risk. Caution is needed in interpreting these results because certainty of the route varies significantly by area. Southeast Asian routes (especially in Vietnam and Thailand) are more flexible than those across Central Asia, but potential changes are unlikely to significantly alter the impacts identified, and the process of project- and site-based evaluation is likely to be the most important for maintaining biodiversity.

Vulnerable Areas

Vulnerable areas varied significantly among taxa because hotspots and threatened areas are different across taxonomic groups, making overarching solutions challenging. Many of the routes proposed through Southeast Asia pose substantial risk to biodiversity and endemism hotspots and these routes (and other planned infrastructure) may facilitate wildlife trafficking. Overall, routes will provide greater access and, therefore, heighten the vulnerability of species and systems across the region. Local planners should consider the economic, social, and ecological acceptability of the route and prioritize the broadest possible suite of options, including mitigation, minimization, and avoidance in consultation with stakeholders.

Routes tracing the Thai-Malay peninsula and the coastline railway of Vietnam potentially pose some of the greatest risks to the largest numbers of species. Protected areas (PAs) do not guarantee protection. For example, in Cambodia many PA downgrading, downsizing, and degazettement (PADDD) events and limited PA coverage mean remaining unprotected ecosystems may be particularly vulnerable (PADDD Tracker [http://www.padddtracker.org/]). Different taxa are differentially vulnerable and potential risks varied along proposed route (Supporting Information). For example, road networks in China were near areas of high diversity for birds and orchids but not other taxa, whereas reptiles were more vulnerable in Thailand and Malaysia. Mammals were most vulnerable to proposed roads in Thailand, Myanmar, and Lao. The proposed route rarely intersected the richest hotspots for any taxon. Model-based hotspots were often smaller and had higher species richness than hotspot maps based on IUCN data (Li et al. 2019). Relative to, for example, Kirchherr et al.'s (2018) results, impacts seemed smaller because true hotspots were smaller and varied by taxa, although they were regionally heterogeneous.

Indian proposed rail routes were near highly diverse areas for mammals and reptiles, but orchids were most vulnerable in China and amphibians in Lao. In Lao 154 bridges, 76 tunnels, and 31 train stations are planned at a cost of over US$8 billion (Lim 2015*b*), and many of these are near highly biodiverse areas. Thus, no panacea is possible, and overarching strategic protections are necessary to protect remaining intact forest along the route, especially in KBAs. Less diverse areas in Russia may also be vulnerable because many of these areas had lower human populations and were until recently less accessible.

Large numbers of KBAs and PAs were near planned routes, and many of the KBAs are not protected. For example, 20% of KBAs were within 7 km of a planned rail route, and 15% were within 1 km, yet only 0.1% of PAs were within 1 km of a planned rail route and 0.6% were within 7 km. Consequently, many key sites may be close to new rail networks and most are unprotected. In contrast, relatively few KBAs were near new roads (0.2% within 1 km and 1.9% within 7 km), and protection of these areas is better (1.1% of PAs within 7 km of proposed routes). Thus, sufficient protection for KBAs near proposed rail routes needs to be provided. Many of these areas face increasing mineral and wood extraction and other development pressures, including increased tourism. Guidelines must be developed for safeguarding these KBAs through either strict protection or adaptive management.

Many hotspots of particularly threatened or data deficient species were also near proposed routes. For example, 58% of the most diverse areas for vulnerable birds were within 7 km of railways, and 71% were within 14 km. Roads posed an equal or greater problem to many species; 28% of the most diverse areas for data deficient mammals were within 14 km of proposed routes. Similar trends existed across taxa, meaning that centers of vulnerability depended on locality, duration, and intensity of disturbance and the ability of species to recolonize following extirpation. Given the close proximity between these areas and parts of the route, caution will be needed to maintain these hotspots.

Maritime BRI routes may bisect marine PAs, and ports connecting marine and terrestrial routes require new development. Ports frequently fall into key areas for migratory wading birds; thus, ineffective management and protection may lead to further declines in the 50 million migratory wading birds that use the East-Australasian Flyway annually (Li et al. 2019). Work on the implications of maritime portions of the route are ongoing (Lee et al. 2018; Qiu et al. 2018), although recent studies largely focus on carbon-emission implications rather implications for marine and coastal diversity.

Supporting Infrastructural Growth

I excluded proposed pipelines in spatial analyses because there was considerable uncertainty in their placement and the threats they pose are from other infrastructure because they lack regular traffic once constructed and do not provide direct access along their routes, as transport infrastructure does. Further analyses are necessary regarding the placement of these pipelines.

Mines, however, are closely associated with proposed routes (Fig. 1), and many proposed roads terminate in or follow areas of peak mining density (i.e., Spain, France, Africa). This suggests areas where new infrastructure will be built rather than enlarged (i.e., northern Russia) may be particularly vulnerable to mining. Given the relationship between mines and proposed routes, it is likely these roads will increase mineral exports. Thus, these mines and their impact on the areas immediately surrounding them will likely increase substantially. Roads have a much tighter relationship with mine density than railways. Thus, increased road networks in Africa, northern Russia, and northern China, where accessibility is currently low, are likely to facilitate infrastructural expansion and natural resource exploitation.

Additional Risks

The resources needed to construct routes or maintain infrastructure has had little consideration. Many portions of the road and railway may be constructed from cement, and there is a significant probability that much of this cement will be sourced from limestone karst, an underprotected ecosystem that supports high levels of endemism (Hughes 2017*a*). Thus, raw-material sourcing policies are essential to the construction of all proposed routes. Southeast Asia especially, with over 800,000 km^2

of karst, may be particularly vulnerable. China alone already uses about 63% of global cement at approximately 1.5 t per capita annually (Hughes 2017*b*). With the increased cement demand for building roads, infrastructural development for the economic belt, and planned increases in cement export, exports can be expected to increase further (Makinen & Law 2016); thus, sourcing policies must explicitly include environmental impact assessment (EIA) associated with major consumables, such as cement. This is especially important for Southeast Asia and southern China, where many species that inhabit karst ecosystems are endemic and most are undescribed (Whitten 2009). Thus, highly endemic karst faunas are at great risk (Clements et al. 2006). Given that high levels of site-specific endemism on karsts (e.g., 12 site-endemic species found at 1 site) and that most species lack inventories (90% of cave invertebrates in China considered undescribed [Whitten 2009]), the loss 1 karst represents the potential loss of unquantifiable numbers of species. The BRI expansion will increase use and demand across the region while the decreased cost of mining karst rather than underground limestone is likely to disproportionately impact these unique systems (Hughes 2017*b*).

How power is generated also requires careful consideration. Increased damming has immense implications for terrestrial and freshwater ecosystems (Lim 2015*a*; Zhang et al. 2017). Other forms of power are also likely to be exploited along the route because BRI countries have 58.8% of the world's oil, 79.9% of its natural gas, and 54% of its coal reserves (Duan et al. 2018).

Overpasses and underpasses may be necessary to minimize roadkill in some areas (Inbar et al. 2002; Zhang 2017*b*). This may be especially important for routes transecting KBAs. Disturbance can profoundly affect species fitness (Kerley et al. 2002); thus, key regions, especially for data deficient and threatened species, should be avoided because their degradation, even with careful implementation, may have disproportionately large effects on species. Hunting, especially in formerly inaccessible areas (e.g., northern Russia) should also be strictly managed and controlled with mechanisms to reduce impact (Braden 2014).

Priorities for Mitigation

Complete avoidance of all key areas for biodiversity along the entire route will be difficult because centers of diversity and endemism vary significantly across taxa and there are insufficient data for the prioritization of all key regions in advance. Thus, appropriate and adequate conservation provisions must be developed on a case-by-case basis but are possible only if comprehensive EIAs are conducted before planning is complete (Table 3). Further deforestation should be prevented wherever possible, as China's Ecological Civilization policy states that biodiversity should be an integral part of planning processes and not simply an "optional extra if the economic and social costs are low enough" (Jin 2008). This is especially important in Southeast Asia, which is already fragmented and subject to some of the highest levels of deforestation and has the highest aggregations of species richness per unit area and of vulnerable or threatened taxa for at least one taxonomic group in every country.

Many parts of routes, especially rail, follow forests along substantial lengths of their course, and the process of construction and subsequent inherently threaten forests and biodiversity. Afforestation, based on sound ecological principles, could be mandated to offset deforestation and forest fragmentation caused by the construction of new infrastructure (Naumann et al. 2011).

Opportunities for Conservation

The proposed BRI enables reexamination of how multilateral agreements (i.e., CBD's Aichi targets) are articulated with national responsibility of countries that fund projects overseas. At present, few mechanisms exist to mediate international investments on the scale of BRI and to reveal how they relate to national policy on maintaining biodiversity, in the same way emissions of CO_2 have been considered (Su & Ang 2014), and telecoupled biodiversity loss requires at least equal attention.

Few EIAs for any part of the route have been published (Khwaja et al. 2018), and those conducted may be moot if no overarching, enforceable policies exist to implement and maintain effective conservation. If national bodies and international funding agencies, such as the Asian Development Bank, Asian Infrastructural Investment Bank, and similar financiers mandate clear EIAs with international oversight and standards, it would vastly improve conservation in the region. Analyses such as mine provide an opportunity to improve protection of many regions that "fall through the gaps" for maintenance of biodiversity (Hughes 2018).

China's Circular Economy shows how sustainability policies can be integrated into economic policies and practices to maintain the provision of key ecosystem services (Ali et al. 2018). Such policies for offsetting threats and the protection of ecosystem services can work effectively if sufficient will exists. Unfortunately, implementation of these policies across China varies, and the policies do not apply to Chinese investments overseas. China's wildlife protection laws could also be broadened to better cover imported wildlife (e.g., provide provisions for how illegally seized wildlife is treated) (Zhang 2016). Such agreements are not novel; as early as the 1990s China and some of its neighbors (i.e., Russia, Mongolia) had bilateral agreements for cooperation on environmental protection (Zhang & Zhang 2017). The revival of such agreements could profoundly lessen negative impacts of the BRI on biodiversity. There is legal precedent for requiring EIA recommendations be shared and for requiring strategic planning (stipulated in Aarhus Convention) (Zhang 2017*a*).

That the majority of KBAs near proposed routes are unprotected and the disparity between where PAs and KBAs fall in relation to the route offers obvious opportunity for protection, and stakeholders will ideally avoid funding development within them. Clear and effective offsetting policies for deforestation and mechanisms to mitigate national emissions through afforestation along parts of the route have the potential to reduce biodiversity loss along large portions of the proposed route. Species may even be able to expand northward along such corridors to better respond to climate change (Hitch & Leberg 2007; Nuñez et al. 2013).

Given that cement production accounts for minimally 15% of China's total emissions (WRI 2018) and their huge use of cement (>100 new cement plants planned along the BRI), emissions may rise considerably (Shen et al. 2015; McNeice 2017). The emissions from new and enlarged mines along the BRI will only exacerbate this, and new mechanisms to counter emissions will be necessary to fulfill China's commitments on the Paris Climate Accord (Davenport 2015; Shao et al. 2016). Afforestation along the BRI route would counter those emissions and ameliorate some of the threats posed by the BRI, but systematic planning and management will still be necessary to mitigate other problems.

Synthesis

The BRI portends a new and significant threat to biodiversity globally because it intersects many biodiverse areas and areas with large aggregations of threatened species, although these patterns differ within each taxon I examined here. Because many of these areas do not overlap among taxa and other areas are likely to be important for taxa I did not consider, solutions are not simple. Policies that ensure rigorous EIAs with international oversight and reportage are needed to safeguard intact ecosystems near the route. Finance offers a practicable way to instigate higher-level policies because many financial institutions have sustainability policies (AIIB 2016) that should be adhered to and that include mandated EIAs before financial approval of development in known KBAs, which may mitigate many potential impacts of development.

Multilateral agreements, such as CBD, should consider both national and embodied diversity losses, and international infrastructure investments should meet the environmental regulations of the host and developers' countries. China has developed a wide suite of approaches, tools, and policies to minimize the impact of infrastructure on the environment domestically, and these same policies and guidelines should be implemented in Chinese infrastructure projects outside the country.

Exploitation of natural resources along the route may increase, and new mine development may need regulation to prevent degradation in currently pristine areas. Likewise, supportive energy infrastructure and the impact of supply chains for building the route also require close scrutiny.

Political and financial decisions on how EIAs are conducted and protection is enforced will determine the outcome; many regions in the vicinity of the route require protection Table 4. Differences in patterns of diversity and vulnerability of different taxa, however, means shortlisting key sites is challenging, and a more holistic framework is needed to ensure sustainable policy decisions are made and enforced along the BRI.

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Supporting Information

Detailed analysis methods (Appendix S1), calculations for cement and limestone use (Appendix S2), proposed road and rail routes overlain with KBAs (Appendix S3), proposed road and rail routes overlain with protected areas (Appendix S4), areas with at least 25, 50, and 75% of maximum diversity for each taxa with proposed BRI road and rail lines shown (Appendix S5), percent diversity within each IUCN Red List category for each taxa within different distances of the proposed BRI road and rail routes (Appendix S6), percentage of most diverse areas per taxa within the 50-km buffer of the proposed BRI road and rail routes (Appendix S7), and per country forest cover and deforestation statistics near road and railway (Appendix S8). 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.

Literature Cited

AIIB (Asian Infrastructure Investment Bank). 2016. Environmental and social framework. AIIB, Beijing, China. Available from https://www.aiib.org/en/policies-strategies/framework-agreements/environmental-social-framework.html (accessed March 2019).

Ali M, Kennedy CM, Kiesecker J, Geng Y. 2018. Integrating biodiversity offsets within Circular Economy policy in China. Journal of Cleaner Production **185:**32–43.

Associated Press. 2018. China's 'One Belt One Road' project hits political, financial hurdles. Hindustan Times, 11 January. Available from https://www.hindustantimes.com/world-news/china-s-one-belt-one-road-project-hits-political-financial-hurdles/story-Ggs6rjv0gAHJTlFg06rQzO.html.

Banerjee D. 2016. China's one belt one road initiative—An Indian perspective. ISEAS Perspective **2016:**1–10.
Braden K. 2014. Illegal recreational hunting in Russia: The role of social norms and elite violators. Eurasian Geography and Economics **555:**457–490.
Bush ER, Baker SE, Macdonald DW. 2014. Global trade in exotic pets 2006–2012. Conservation Biology **283:**663–676.
Clements R, Sodhi NS, Schilthuizen, M, Ng, PK. 2006. Limestone karsts of Southeast Asia: Imperiled arks of biodiversity. BioScience **56:**733–742.
Coffin AW. 2007. From roadkill to road ecology: A review of the ecological effects of roads. Journal of Transport Geography **155:**396–406.
Das M. 2014. Cement, now the preferred choice of Road Ministry. The Hindu, 1 July. Available from https://www.thehindubusinessline.com/news/Cement-now-the-preferred-choice-of-Road-Ministry/article20809403.ece.
Dasgupta S, Pasricha A. 2017. Pakistan, Nepal, Myanmar back away from Chinese projects. VOANews, 4 December. Available from https://www.voanews.com/a/three-countries-withdraw-from-chinese-projects/4148094.html.
Davenport C. 2015. Nations approve landmark climate accord in Paris. The New York Times, 12 December.
Duan F, Ji Q, Liu BY, Fan Y. 2018. Energy investment risk assessment for nations along China's Belt & Road Initiative. Journal of Cleaner Production **170:**535–547.
Espinosa S, Branch LC, Cueva R. 2014. Road development and the geography of hunting by an Amazonian indigenous group: consequences for wildlife conservation. PLOS ONE **9:**e114916. https://doi.org/10.1371/journal.pone.0114916.
Foggin JM. 2018. Environmental conservation in the Tibetan Plateau region: lessons for China's Belt and Road Initiative in the mountains of Central Asia. Land **72:**52.
Gregory R, et al. 2012. Deliberative disjunction: expert and public understanding of outcome uncertainty. Risk Analysis **32:**2071–2083.
Hitch AT, Leberg PL. 2007. Breeding distributions of North American bird species moving north as a result of climate change. Conservation Biology **21:**534–539.
Huang Y, Fischer TB, Xu H. 2017. The stakeholder analysis for SEA of Chinese foreign direct investment: The case of 'One Belt, One Road' initiative in Pakistan. Impact Assessment and Project Appraisal **352:**158–171.
Hughes AC. 2017*a*. Mapping priorities for conservation in Southeast Asia. Biological Conservation **209:**395–405.
Hughes AC. 2017*b*. Understanding the drivers of Southeast-Asian biodiversity loss. Ecosphere **8**. https://doi.org/10.1002/ecs2.1624.
Hughes AC. 2018. Have Indo-Malaysian forests reached the end of the road? Biological Conservation **223:**129–137.
Inbar M, Shanas U, Izhaki I. 2002. Characterization of road accidents in Israel involving large mammals. Israel Journal of Zoology **483:**197–206.
IUCN (International Union for Conservation of Nature). 2018. IUCN Red List assessor training. IUCN, Gland Switzerland. Available from https://www.conservationtraining.org/course/index.php?categoryid=40 (accessed March 2019).
Jin Y. 2008. Ecological civilization: From conception to practice in China. Clean Technologies and Environmental Policy **10:**111–112.
Kerley LL, Goodrich JM, Miquelle DG, Smirnov EN, Quigley HB, Hornocker MG. 2002. Effects of roads and human disturbance on Amur tigers. Conservation Biology **161:**97–108.
Khwaja MA, Saeed S, Urooj M. 2018. Preliminary environmental impact assessment EIA study of China-Pakistan Economic Corridor CPEC northern route road construction activities in Khyber Pakhtunkhwa KPK, Pakistan. Available from https://www.researchgate.net/publication/322626087_ (accessed March 2019).
Kirchherr JW, Repp L, van Santen R, Verweij PA, Hu X, Hall J. 2018. Greening the Belt and Road initiative WWF's recommendations for the finance sector. World Wildlife Fund, Gland, Switzerland. Available from https://dspace.library.uu.nl/handle/1874/362894 (accessed March 2019).
Laurance WF, Goosem M, Laurance SG. 2009. Impacts of roads and linear clearings on tropical forests. Trends in Ecology & Evolution **24:**659–669.
Lechner AM, Chan FKS, Campos-Arceiz A. 2018. Biodiversity conservation should be a core value of China's Belt and Road Initiative. Nature Ecology & Evolution **2:**408.
Lee PTW, Hu ZH, Lee SJ, Choi KS, Shin SH. 2018. Research trends and agenda on the Belt and Road B&R initiative with a focus on maritime transport. Maritime Policy & Management **453:** 282–300.
Li J, Hughes AC, Dudgeon D. 2019. Mapping wader biodiversity along the East Asian—Australasian Flyway. PLOS ONE **14:**e0210552. https://doi.org/10.1371/journal.pone.0210552.
Lim ACH. 2015*a*. Laos and the Silk Road economic belt. Eurasia Review, 30 July. Available from http://www.eurasiareview.com/30072015-laos-and-the-silk-road-economic-belt-analysis/.
Lim ACH. 2015*b*. China's "belt and road" and Southeast Asia: challenges and prospects. Jati-Journal of Southeast Asian Studies **20:**3–15.
Makinen J, Law V. 2016. China's bold gambit to cement trade with Europe–along the ancient Silk Road. Los Angeles Times, 1 May. Available from http://www.latimes.com/world/asia/la-fg-china-silk-road-20160501-story.html.
McNeice A. 2017. China to build 100 cement plants in Belt and Road region. China Daily, 13 December. Available from http://www.chinadaily.com.cn/a/201712/13/WS5a3015c8a3108bc8c672b094.html.
MOFCOM. 2017. 2015年1-11月中国与'一带一路'相关国家经贸合作情况. The economic and trade cooperation between China and the 'Belt and Road' countries. Ministry of Commerce of the People's Republic of China, Beijing. Available from http://www.mofcom.gov.cn/article/tongjiziliao/dgzz/201512/20151201213367.shtml (accessed March 2019).
Naumann S, Davis M, Kaphengst T, Pieterse M, Rayment M. 2011. Design, implementation and cost elements of Green Infrastructure projects. Final report. European Commission, Belgium.
Nuñez TA, Lawler JJ, McRae BH, Pierce DJ, Krosby MB, Kavanagh DM, Tewksbury JJ. 2013. Connectivity planning to address climate change. Conservation Biology **27:**407–416.
Qiu X, Wong EY, Lam JSL. 2018. Evaluating economic and environmental value of liner vessel sharing along the maritime Silk Road. Maritime Policy & Management **453:**336–350.
Shao S, Liu J, Geng Y, Miao Z, Yang Y. 2016. Uncovering driving factors of carbon emissions from China's mining sector. Applied Energy **166:**220–238.
Shen W, Cao L Li Q, Zhang W, Wang G, Li C. 2015. Quantifying CO_2 emissions from China's cement industry. Renewable and Sustainable Energy Reviews **50:**1004–1012.
Su B, Ang BW. 2014. Input–output analysis of CO_2 emissions embodied in trade: A multi-region model for China. Applied Energy **114:**377–384.
Tracy EF, Shvarts E, Simonov E, Babenko M. 2017. China's new Eurasian ambitions: The environmental risks of the Silk Road Economic Belt. Eurasian Geography and Economics **581:**56–88.
VOA Learning English. 2018. China's Silk Road Plan facing problems. VOA Learning English, 15 January. Available from https://learningenglish.voanews.com/a/china-silk-road-plan-facing-problems/4203867.html.
Whitten T. 2009. Applying ecology for cave management in China and neighbouring countries. Journal Applied Ecology **46:**520–523.
WRI (World Resources Institute). 2018. Controlling CO_2 emissions in China's cement industry. WRI, Washington, D.C. Available from https://www.wri.org/our-work/top-outcome/controlling-co2-emissions-china%E2%80%99s-cement-industry (accessed March 2019).

Zapata P, Gambatese JA. 2005. Energy consumption of asphalt and reinforced concrete pavement materials and construction. Journal of Infrastructure Systems **111:**9–20.

Zhang L. 2016. China: New wildlife protection law. Global Legal Monitor, 5 August. Available from http://www.loc.gov/law/foreign-news/article/china-new-wildlife-protection-law/.

Zhang K. 2017*a*. Right to information about, and involvement in, environmental decision making along the Silk Road Economic Belt. The Chinese Journal of Comparative Law **51:**58–78.

Zhang X. 2017*b*. Political ecology approaches to develop wildlife loss mitigation strategies: A case study of mitigation strategies for urban and regional planning to address wildlife vehicle collisions on existing roads. PhD dissertation. University of Delaware, Newark, Delaware.

Zhang N, Liu Z, Zheng X, Xue J. 2017. Carbon footprint of China's belt and road. Science **357:**1107–1107.

Zhang X, Zhang S. 2017*b*. China-Mongolia-Russia economic corridor and environmental protection cooperation. R-Economy **3:**161–166.