China Biodiversity Outlook

Hill, Samantha; Harfoot, Mike; Malek, Ziga; Faustino, Claudia; Gosling, Joe; Arnell, Andy; Cannanure, Vignesh; Wentworth, Julia; Danks, Fiona; Xu, Cecilia; Qing, Chen; Wang, Victoria; Meng, Han

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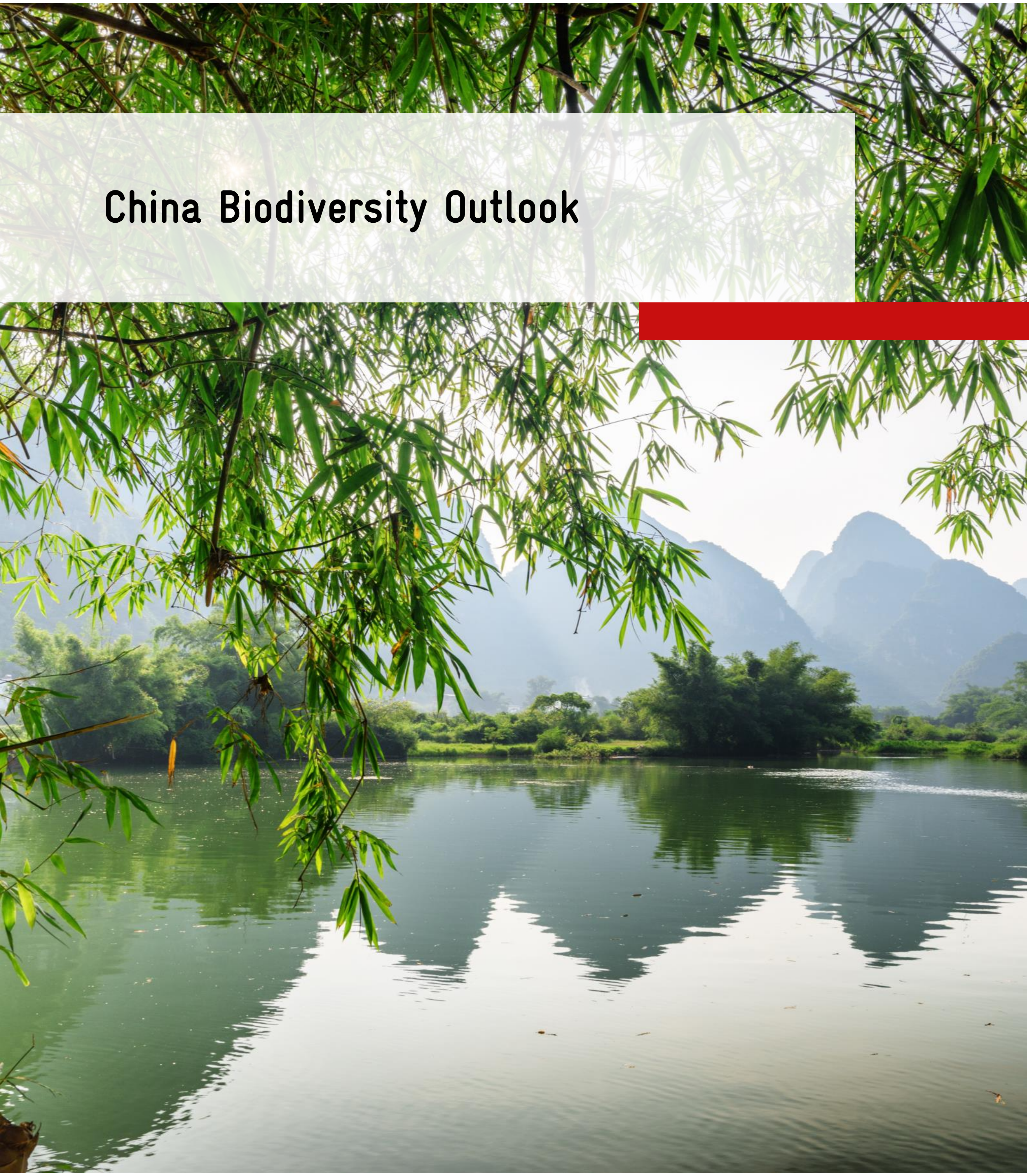
China Biodiversity Outlook



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E info@giz.de
I www.giz.de/en

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Authors:
Samantha Hill (UNEP-WCMC), Mike Harfoot (UNEP-WCMC), Ziga Malek (Vrije Universiteit Amsterdam),
Claudia Faustino (UNEP-WCMC), Joe Gosling (UNEP-WCMC), Andy Arnell (UNEP-WCMC),
Vignesh Cannanure (UNEP-WCMC), Julia Wentworth (UNEP-WCMC), Fiona Danks (UNEP-WCMC),
Cecilia Xu (WCMC Beijing), Chen Qing (WCMC Beijing), Victoria Wang (WCMC Beijing) and Han Meng (UNEP-WCMC)

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UNEP-WCMC, 219 Huntingdon Road, Cambridge, CB3 0DL, UK.

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Beijing, 2022

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Abbreviations

AIC	Akaike Information Criterion
AIM	Asia-Pacific Integrated Model
AOH	Area of Habitat
BII	Biodiversity Intactness Index
BfN	Federal Agency for Nature Conservation
BMUV	Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection
CBD	Convention on Biological Diversity
CNCBC	China National Committee on Biodiversity Conservation
CRAES	Chinese Research Academy of Environmental Sciences
DD	Data Deficient
ECA	Equivalent Connected Area
FECO	Foreign Environmental Cooperation Center
GBF	Global Biodiversity Framework
GDP	Gross Domestic Product
GEZ	Global Ecological Zones
GIS	Geographic Information Systems
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
GLOBIOM	Global Biosphere Management Model
IAMs	Integrated assessment models
IBN	Institute for Biodiversity - Network e.V.
IKI	International Climate Initiative
IMAGE	Integrated Model to Assess the Global Environment
IPBES	Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature (Red List)
LC	Least Concern
MAgPIE	Model of Agricultural Production
MEE	Ministry of Ecology and Environment
MFA	Ministry of Foreign Affairs
MNR	Ministry of Natural Resources
NBSAP	National Biodiversity Strategy and Action Plan
NDRC	National Development and Reform Commission

NIES	Nanjing Institute of Environmental Sciences
NT	Near Threatened
PC	Probability of Connectivity
PREDICTS	Predicting the Responses of Ecological Diversity in Changing Terrestrial Systems
RCP	Representative Concentration Pathway
SDGs	Sustainable Development Goals
SGBC	Sino-German Biodiversity Component
SGEP	Sino-German Environmental Partnership Project
SPS	Spatial Population Scenarios
SSPs	Shared Socioeconomic Pathway scenarios
STIO	State Council Information Office of the People's Republic of China
UNEP-WCMC	United Nations Environment Programme World Conservation Monitoring Centre
UNESCO	United Nations Educational, Scientific and Cultural Organization

Executive Summary

Crystal balls themselves might be the stuff of mythology but the foresight that legends say they granted is now very real. No magic is needed. By looking at trends and calculating probabilities, ecologists can determine what the future will look like. The key variable is human behaviour. The policies enacted by governments and the actions taken by citizens are the main factors that determine whether the future will be one where humanity lives alongside nature in harmony or where people face apocalypse. All nations face difficult decisions in the years ahead but, unlike others that seek to make minor adjustments to accommodate the environment, China is rising to the challenge and ambitiously seeking to transform itself into a truly ecological civilisation.

One of just seventeen countries ranked as mega-biodiverse, China has 19 types of marshland, 52 types of deserts, 77 types of meadows, 212 types of forests and much more. It is home to 38,631 animal species. It has 44,041 plant species living within its borders, only Brazil and Colombia have more. Yet, much of this diversity sits upon a knife's edge. China is experiencing rapid economic development. Urban environments are spreading, industrial activity is increasing and invasive pests are causing ever more serious problems. Nearly half of all wild animals in the country are in decline. An estimated 11% of all plants are now listed as threatened. The country is working feverishly to counter these problems and has set itself bold goals. By 2035, it expects to have shielded 60% of its wetlands from development, it will have increased its overall forest cover to represent 26% of its land area and it will grow its protected area network to support the rescue of its endangered wildlife. Encouraging as these efforts are, there are still challenges to be met.

As plantations of single tree species are put in place to restore degraded lands, pest resistance is waning. Lush ecosystems that once filtered rain through soil bound tightly together by the roots of plants and which yielded vital supplies of fresh water to communities are becoming rarer. Coastal and marine habitats that have provided fish to hungry families for centuries are being lost. The list is long. China's future depends upon turning the tide. There is little question about what the future of China needs to be for its people and ecosystems to flourish. The challenge is finding the right path to get there.

Without access to an actual crystal ball, researchers at the United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC) in collaboration with partners Nanjing Institute of Environmental Sciences (NIES), Chinese Research Academy of Environmental Sciences (CRAES), and Foreign Environmental Cooperation Center (FECO) in China and Vrije Universiteit Amsterdam in Netherlands crunched numbers to work out the actions that need to be taken to obtain a bright future for China. They considered two critical ways in which human behaviour could shape what is to come.

The first way, which is known as "the green path," involves the people of China shifting towards lives that are supportive of nature. Under this scenario, the current emphasis on growing the economy would be redirected towards improving the well-being of people. This would result in (among other things) reduced consumerism, reduced consumption of meat and reduced energy use. Investments in health and education would support this sort of demographic shift. Population growth would diminish.

In counterpoint to the green path is the business as usual scenario. As the name implies, if the people of China choose this option then the population will continue to grow at moderate levels, consumption of resources will continue unsustainably and wilderness will be further degraded. These problems will be mildly alleviated by some environmental protection and restoration but the overall trend would be negative.

Separate from the choices that the people of China make are the policies that their government chooses to implement. The researchers conducted a review of Chinese legislation and policies that would yield measurable environmental results. While everything that they considered was varied and complex, the team mostly focused on policies that resulted in measurable changes on the ground, such as the restoration of grasslands and forests and establishment of protected areas

Once the researchers identified the two parameters, green path vs business as usual and implementation of environmental policy or not, the number crunching began. Using cutting-edge computer models, it is possible to work out how land will be used in the future based upon both the actions of people and governments. This land use information can then be worked with to predict which ecosystems are going to be present, how interconnected they will be, what their biodiversity will be like and how much carbon the land will be able to store.

The team fed all of the necessary information into their future-predicting systems. Since there were two parameters selected by the researchers, the computers provided four results for what China would look like in 2035. These results were green path with no government policy implementation, green path with government policy implementation, business as usual with no government policy implementation and business as usual with government policy implementation.

The researchers found that business as usual combined with no government policy implementation would be a disaster. As populations grow, demand for more resources and expansion outside of current settlements would lead to extensive ecosystem destruction. Extinctions would soar and ecosystem health would decline. The ecological literature indicates that this degradation would result in increased disease outbreaks, floods and wildfires. This confirms what ecologists have long expected would be China's fate if corrective actions are not taken.

In striking contrast to this dark scenario is the future that will come to pass if the green path is followed by the people of China as the government also enacts environmentally protective polices. Under these circumstances, changes in diet reduce demand for resources while technological advancement in sustainable agricultural management increases resource availability without more land needing to be developed. Similarly, urban expansion is minimised as people choose to have smaller families while vast tracts of wilderness are shielded by government policies. The model suggests that roughly a third of all species in China would see their habitat ranges expand by at least 30% under these circumstances. It also predicts that natural disasters caused by ecosystem damage would be significantly mitigated.

The other two results reveal more mixed futures. If the people of China shift to more environmentally supportive behaviours but the government does nothing to protect wilderness, farms and fisheries will end up being built in locations that are ideal for maximum food production with no attention being made to the ecosystems being converted for this use. This tactic reduces the land that the agricultural industry needs but, in the process of obtaining this efficiency, it wipes out vital ecosystems. The reverse scenario, where the government protects lands but people do not change their ways, will leave China with well protected forests and grasslands that are effectively islands surrounded by an intensive agricultural industry, virtual deserts in terms of biodiversity.

The path that must be followed is clear. Wilderness must be protected and restored, but this alone is not enough. People must change their ways too. To ensure that China can continue to reap the benefits provided by the natural world, ecosystems must be woven seamlessly between all lands both developed and reserved. For this to happen, extensive economic and social transformation is essential. If this is achieved, China can expect a bright future of living hand in hand with nature.

This report and the modelling framework have been developed as part of a technical support project on method development and decision support. They are an output from the Sino-German Biodiversity Component (SGBC) under Sino-German Environmental Partnership Project (SGEP) Phase II, which is funded through the International Climate Initiative (IKI) of the Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) of the Federal Republic of Germany and implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

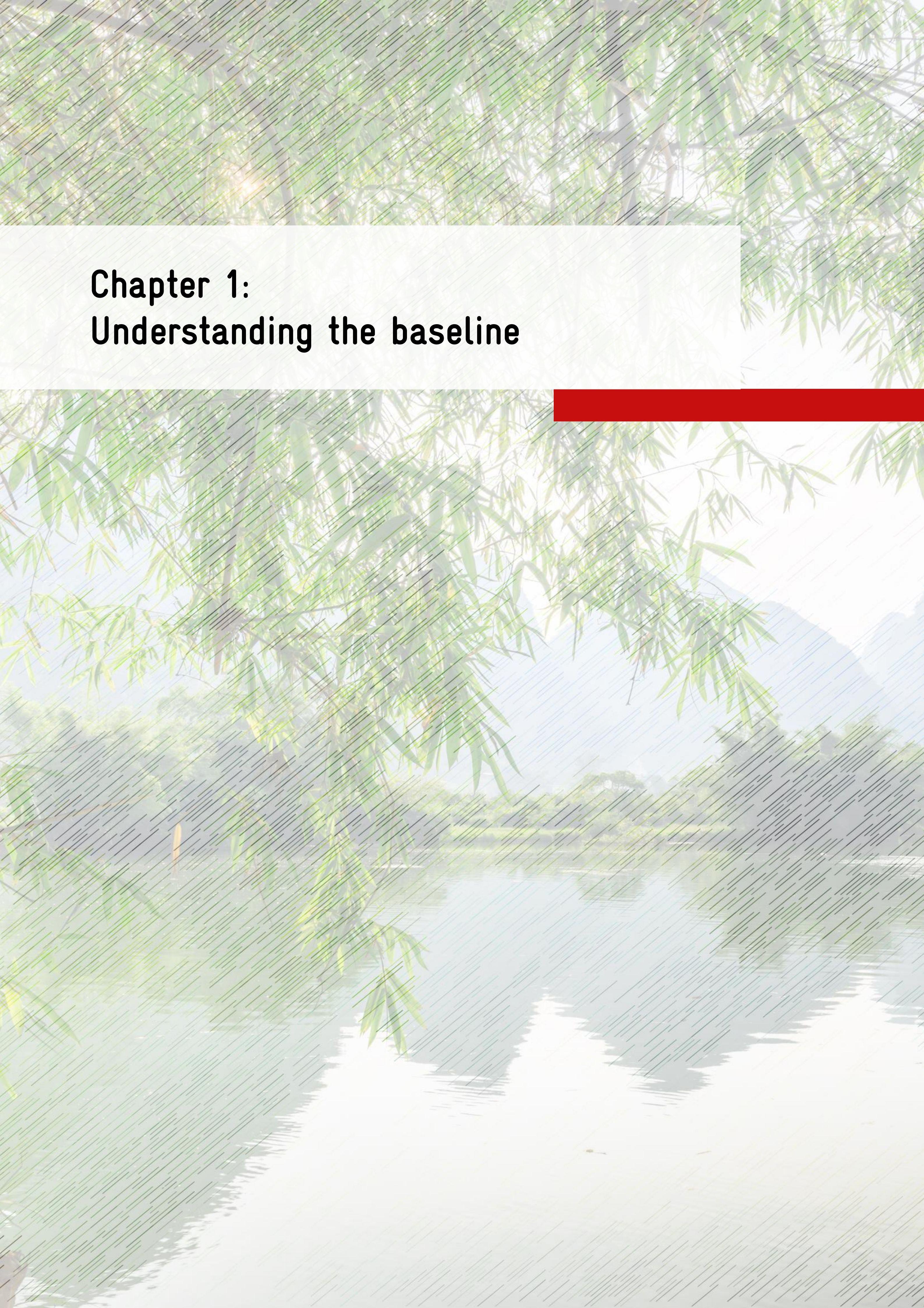
Objectives of this report

This report explores the short and longer-term implications of the implementation of China's conservation policies using a range of land use and biodiversity models. The report aims to:

- Inform Chinese policy makers as to the biodiversity impact of a selection of current conservation policies;
- Explore regional differences in the biodiversity impacts of the selected current conservation policies; and
- Provide a modelling framework that can be applied to inform the design and implementation of future policies or goals, for instance, the Convention on Biological Diversity's post-2020 global biodiversity framework targets and goals.

This report is set out as follows: Chapter 1 provides an overview of the state of biodiversity, biodiversity related policies as well as their implementation progresses and challenges within China drawing upon a selection of China's released policy documents; Chapter 2 describes the methodology for projecting biodiversity futures using land use, biodiversity and ecosystem services models; Chapter 3 presents the analytical results at national level; Chapter 4 dives into biodiversity futures based on two selected cases, giant panda and Hainan Province; and Chapter 5 provides a conclusion on our key findings and what implications of policy implementation on the ground based on modelling results.

Chapter 1:
Understanding the baseline



1 Understanding the baseline

1.1 Background and context

This chapter sets the scene for the China Biodiversity Outlook (hereafter ‘the Outlook’), providing information on the current state of biodiversity in China and analysing how biodiversity-relevant policies have been implemented in the past. The chapter also outlines biodiversity policies that are being implemented, or will be implemented in the future, with an aim to provide the background to the narratives of the scenarios that will be described in the following chapters.

Upon consultations with partners under the Sino-German Biodiversity Component (SGBC) and to ensure consistency and credibility in terms of data sources, the information reported in this chapter has been obtained through a selection of key national reports and policy documents on biodiversity officially released by China. These documents include: China National Biodiversity Conservation Strategy and Action Plan (MEE, 2010), Sixth National Report for the Convention on Biological Diversity (MEE, 2018), National Master Plan for the Protection and Restoration of Important Ecosystems (2021-2035) (NDRC and MNR, 2020), Biodiversity Conservation in China (STIO, 2021), Building a Shared Future for All Life on Earth: China in Action (MFA and MEE, 2021), and Opinions on Further Strengthening the Protection of Biodiversity (General Office of the Central Committee of the Communist Party of China, General Office of the State Council, 2021).

It should be noted that one caveat for the biodiversity baseline analysis presented in Chapter 1 is that, due to the constraint of the project's scope, the review presented in this chapter is only based on literature review and is therefore largely constrained to the available data sources as listed above.

1.2 China’s rich biodiversity

The Convention on Biological Diversity defines "biological diversity" as “the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems”[1] .The Ministry of Ecology and Environment of China (MEE) recognises humanity’s reliance on biodiversity in the China National Biodiversity Conservation Strategy and Action Plan (2011-2030) (MEE, 2010), stating that biodiversity provides the foundation for human survival and sustainable social and economic development; and safeguards ecological safety and food security.

China is one of the seventeen mega-biodiverse countries in the world (Mittermeier et al. 1997). Its richness of biodiversity and high levels of endemism are supported by the country’s great land area, complex topography and coverage by diverse climate zones. With regards to terrestrial ecosystems, China has 212 types of forests, 113 types of shrubland, 36 types of bamboo forest, 19 types of marshland, 18 types of mangrove, 77 types of meadows, 55 types of steppe, 17 types of alpine tundra and 52 types of deserts (MEE, 2018). There are also four major types of natural wetlands, including marshlands, offshore and coastal wetlands, riverine coastal wetlands, and lake wetlands. There are four distinct marine ecosystems in China, namely the Yellow Sea, East China Sea, South China Sea and Kuroshio waters (MEE, 2018). In terms of species diversity, the number of known species and sub-species is 92,301, including 38,631 species of animals, 44,041 species of plants, and 4,273 species of fungi (MEE, 2018). The number of higher plant species in China ranks third in the world, second only to Brazil and Colombia (MEE, 2018). China has the largest number of gymnosperms in the world (MEE, 2018). There are more than 7,300 species of vertebrates in China, accounting for 11% of the world's total species,

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[1] CBD Article 2. Use of Terms - https://www.cbd.int/convention/articles/?a=cbd-02

including 673 mammals, ranking first in the world (MEE, 2018). China's marine areas have abundant species richness with over 28,000 species recorded, accounting for 11% of the world's total known marine species (MEE, 2018).

China has a large number and proportion of endemic species. For instance, 56.05% of vascular plants in China are endemic including many endemic plant species found within three regions referred to as the East Sichuan-West Hubei endemic centre, the West Sichuan-Northwest Yunnan endemic centre, and the South-eastern Yunnan-West Guangxi endemic centre (MEE, 2018). There are 150 species of endemic mammals in China, accounting for 22.29% of the total number of mammals in the country, 272 species of endemic amphibians in China, accounting for 66.67% of the total number of amphibians in the country, and 957 species of endemic fish species in the inland waters, accounting for 66.32% of the total number of freshwater fish in the country (MEE, 2018).

Furthermore, China is home to many economically important species. China is the country of origin of significant crops such as rice, soybean, and various wild and cultivated fruit trees (MEE, 2018). China has more than 1,300 species of cultivated crops, nearly 2,000 wild crop-relatives, and more than 1,000 economically important tree species (MEE, 2018). China also holds an outstanding diversity of breeds of domesticated animals (MEE, 2018).

1.3 Threats to biodiversity in China

Biodiversity in China, like in the rest of the world, is under significant threat, facing multiple pressures and challenges. China is undergoing rapid economic development leading to fast expansion of industrial and urban infrastructure. This development, coupled with the increased consumption of a growing population, and exacerbated by climate change, has driven biodiversity loss through pressures such as the conversion or degradation of natural habitats, overexploitation of natural resources, environmental pollution, and increasing numbers of invasive alien species (MEE, 2010; MEE, 2018; NDRC & MNR, 2020).

Ninety percent of China's grasslands have been found to be degraded by varying degrees (MEE, 2010) including destruction by rats which was found to effect around 7.2% of the country's total grassland area.

Overharvesting of fisheries has led to declines in fish abundance and to changes in the composition of populations, which are now disproportionally composed of young and smaller-sized fish (MEE, 2018). The cohort of juvenile animals of the four most commonly fished species in the Yangtze River was found to be approximately 3% of those in the 1960's (MEE, 2018). Over 100 fish species in the Pearl River that were once common are now rare or endangered (MEE, 2018).

The high economic value of some species of wild plants and animals due to herbal, food or recreational uses has resulted in illegal trade. It has been estimated that over one hundred species in China are at put at risk due to illegal trade (MEE, 2018).

Air quality has been degraded by, among others, the burning of coal, vehicle emissions, and agriculture, Water quality has likewise been degraded by agricultural emissions as well as the discharge of large amounts of industrial and municipal wastewater (MEE, 2018). River pollution, together with pollution directly released into marine environments, has dramatically degraded marine habitats. For example, of 20 marine regions sampled, including estuaries, bays, marshlands, coral reefs, mangroves and seagrass beds, only four were found to be in good condition (MEE, 2018).

Due to China's rich trading network, China is one of the countries in the world most affected by invasive alien species with 51 of the 100 harmful invasive alien species listed by the IUCN found in China and 560 species of invasive alien species detected overall (MEE, 2018).

Such anthropogenic pressures have resulted in the endangerment of many species (MEE, 2010). It is estimated that 15-20% of wild higher plants in China are threatened (MEE, 2018). The status of endangered wild animals continues to worsen, with about 44% of wild animals declining (MEE, 2018).

The China Biodiversity Red List assessments show (MEE, 2018):

- 10.9% of the total number of higher plants assessed are threatened; of those, 51.0% are gymnosperms and 11.4% are angiosperms;
- 21.4% of the total number of vertebrates assessed are threatened with 10.6% of birds assessed found to be threatened, 29.7% of reptiles, 43.1% of amphibians, and 20.3% of freshwater fishes;
- 1.04% of the total species of Macrofungi assessed are threatened which included 57 endemic macrofungi.

China's Sixth National Report for CBD states that the Yangtze river dolphin (Lipotes vexillifer), the Chinese paddlefish (Psephurus gladius) and reeves' shad (Macrura reevesi) have become functionally extinct, and the narrow-ridged finless porpoise (Neophocaena asiaeorientalis) and Chinese sturgeon (Acipenser sinensis) have become extremely endangered, due to the conversion of freshwater systems to human uses (MEE, 2018).

1.4 Domestic biodiversity policy and responses

China's biodiversity policies have undergone two general phases, the exploration phase, from the 1980s until 2010; and the proactive phase, from 2010 to present (Table 1).

Under the exploration phase, China's formal biodiversity policies could be traced back to 1987 when the "Chinese Programme for Nature Protection" was released. In 1992, China signed up to the UN Convention on Biological Diversity (CBD) as one of the very early signatories. As a response to the ratification of the CBD in the following years, a series of policy measures to enhance biodiversity protection in China were released. In this phase, biodiversity started to gain attention in China's major development strategy. For example, the 11th Five-Year Plan (2006-2010) clearly emphasized the importance of key ecological function areas and prioritized protection of these areas over economic development.

In 2010, China released its first National Biodiversity Strategy and Action Plan for 2011-2030 (hereafter 'NBSAP 2011-2030'). This identifies the country's biodiversity goals, strategy and action plan until 2030. In many ways, this marks the start of China's more proactive development phase regarding biodiversity policies. The guidance includes multiple quantitative goals for 2025, such as:

- forest coverage increased to 24.1% of the total land area;
- grassland coverage increased to 57% of the total land area;
- 55% of current wetland extent protected (General Office of the Central Committee of the Communist Party of China, General Office of the State Council, 2021).

Table 1. Biodiversity Policy Phases in China showing key events and release of major reports on Biodiversity.

Biodiversity Policy Phase 1: 1987-2010, Exploration phase

1987: Chinese Programme for Nature Protection

1992: China signed up to CBD

1994: Adoption of China's Biodiversity Conservation Action Plan

1999: China released its First National Conditions of Biodiversity Report

Biodiversity Policy Phase 2: since 2010, Proactive phase

2010: China's First National Biodiversity Strategy and Action Plan (NBSAP, 2011-2030)

2011-2015, 12th Five-Year Plan

2016-2020, 13th Five-Year Plan

2018: Sixth National Report for the CBD

2020: National Master Plan for the Protection and Restoration of Important Ecosystems (2021-2035)

2021-2025, 14th Five-Year Plan and Vision for 2035; with various emphasis on ecological environment protection

2021-2022 Host and Presidency of the Fifteenth Conference of the Parties to the CBD (COP15, Kunming)

In 2012, the formal inclusion of the "Ecological Civilisation" concept into the Party Constitution at the 18th National Congress of the Communist Party of China was an important milestone for China's biodiversity policies as this, for the first time in China, clearly demonstrated the highest level of political position regarding the protection of biodiversity and ecological environment.

Since 2012, China's biodiversity policies have been significantly and systematically strengthened. For example, biodiversity conservation and sustainable use are further and increasingly integrated into China's 12th Five-Year Plan (2011-2015), 13th Five-Year Plan (2016-2020) and most recently its 14th Five-Year Plan (2021-2025).

In June 2020, China's National Development and Reform Commission (NDRC) and the Ministry of Natural Resources (MNR) jointly released the "National Master Plan for the Protection and Restoration of Important Ecosystems (2021-2035)" (herein referred to as the "Master Plan"). This important overarching policy framework extends China's national strategy on ecosystem protection and restoration and specifies a series of time-bound ecosystem quality improvement targets by 2035.

The Master Plan calls for the improvement of ecosystem health in recognition that this will increase the capacity of ecosystem services to provide for society. Multiple quantitative goals for 2035 are listed (NDRC and MNR, 2020), such as:

- expansion of forest coverage to 26% of China's terrestrial area;
- expansion of forest stock to 21 billion cubic meters;
- natural forest area stabilises at around 200 million hectares;
- area with comprehensive control of soil erosion is increased by 56.4 million hectares, and more than 75% of treatable, desertified land is treated;
- 60% of grassland areas have comprehensive vegetation cover;

- wetland area is not reduced and 60% of wetlands are protected;
- nature reserves will occupy more than 18% of the total land area;
- marine ecological degradation will be fully turned around;
- at least 35% of coastlines will be kept in natural status;
- endangered wild animals and plants and their habitats will be fully protected.

Furthermore, the Master Plan also identifies nine major ecosystem protection and restoration projects across the country as well as highlights seven key ecosystem areas in China. Key ecosystem areas are defined as areas of great ecological, economic, and security importance to China which have long been exposed to severe development pressures. Vital ecosystem-related national strategies and initiatives have supported the identification of the key ecosystem areas including the Ecological Conservation Redlining implementation and the new Protected Area System formation (NDRC and MNR, 2020).

In order to balance the need for sustainable development and to ensure the integrity of natural habitats, the Master Plan takes into consideration of the connectivity of species' habitats, balanced with understanding of pivotal cross-regional economic hubs in China, including the Beijing-Tianjin-Hebei Region, Yangtze River Economic Zone, among others (NDRC and MNR, 2020).

According to the Master Plan, in its initial five years (2021-2025), actions will be focused on addressing a series of core ecological issues within the National Key Ecological Zones, Ecological Conservation Redlining areas, and Key National Nature Reserves; from 2026 to 2035, the nine major ecosystem protection and restoration projects are expected to be under full implementation. The Master Plan emphasizes the urgency and importance of shaping an "Ecological Civilization" whilst paving the way towards the long-term strategic goals of realizing "Socialist Modernization" and achieving a "Beautiful China" by 2035 (NDRC and MNR, 2020).

1.5 Progress towards policy targets and challenges

Plans and programmes on biodiversity conservation have been implemented. Following the issuance of the Biodiversity Conservation Action Plan in 1994, the Government of China published in succession the China Nature Reserves Program (1996-2010), China Master Plan for Ecological Conservation, China Program for Ecological Environment Conservation and China Program for Conservation and Use of Biological Resources (2006-2020), among others.

In 2010, the CBD set 20 targets to slow, and then halt, the loss of biodiversity. Those targets were agreed in Aichi, Japan, and are as such known as the "Aichi Biodiversity Targets"[2] Since the adoption of the Aichi Biodiversity Targets, biodiversity conservation in China has achieved much through statutory and regulatory mechanisms. For example, China issued a series of laws that administer protection on individual species as well as entire habitats (e.g., the Wild Animal Protection Law, the Forest Law, and the Law on the Quarantine of Import and Export of Animals and Plants).

China has also issued a series of administrative regulations including the Regulation on Nature Reserves, the Regulation on Biosafety Management of Agricultural Genetically Modified Organisms, and the Regulation on the Management of Trade in Endangered Wild Animals and Plants. In partnership, related sectoral departments and some provincial governments have adopted corresponding rules, local regulations, and codes of conduct.

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[2] Aichi Biodiversity Targets - https://www.cbd.int/sp/targets/

There has been various progresses related to the coordination mechanisms for biodiversity conservation. For example, China established a Coordinating Group for the Implementation of the CBD and an Inter-ministerial Joint Meeting for Protection of Biological Resources. A national level coordinating mechanism, namely China National Committee on Biodiversity Conservation (CNCBC), for biodiversity conservation and implementation of the CBD and related agreements has been established. The Committee calls upon each local government to establish coordinated mechanisms for biodiversity conservation including the identification of conservation goals and the implementation of actions. The national government is accountable for coordination among ministerial departments with common responsibilities in biodiversity conservation as well as the exchange of information (MEE, 2010).

The capacities of biodiversity identification, research and monitoring have been enhanced. Relevant departments organized numerous species surveys at national or regional levels and built a species distribution database, covering 2,376 county-level administrative units and more than 34,000 km of transect surveys. Species inventories, such as the Flora of China[3], the Fauna of China[54], and the China Red Data Book of Endangered Animals, have also been published (MEE, 2010). In addition, China has put in place biodiversity monitoring and observation networks and an online platform to collect biodiversity observations and to accurately map the spatial distribution of wildlife (STIO, 2021).

The prevention and control of invasive alien species has been further regulated through collaborative groups as well as an inter-departmental committee for risk analysis of animal and plant quarantine. Relevant departments have also established special agencies for the prevention and control of invasive alien species (MEE, 2010).

Such policy responses have resulted in the restoration of natural habitats. China has achieved the largest growth in forest resources among all countries in the world (STIO, 2021). However, according to China's NBSAP 2011-2030, the monopoly of forest plantations in China has been a challenge and has led to low pest resistance of forests, among other issues (MEE, 2010). Satellite data shows that more than a quarter of the newly added green space in the world between 2000 and 2017 was in China, making it the largest single contributor to the greening of the global landscape (MFA and MEE, 2021). Wetlands have also been restored, with the ecological quality of 233,300 ha of wetlands improved, and 51,000 ha of wetlands recovered from agricultural use (MEE, 2018).

The coverage of marine and terrestrial protected areas has increased, with over 90% of terrestrial ecosystem types included within protected areas (MEE, 2018).

Some species are also recovering. The number of giant pandas has nearly doubled since the 1980's (MEE, 2018). Crested ibis have also undergone a dramatic recovery, with 7 individuals known in 1981 to over 2,600 in recent surveys (MEE, 2018). Przewalski's gazelle has increased from less than 200 in 2003 to 2,010 in recent years (MEE, 2018).

China has also increased financial input and effort in technology research and development to improve the capacity for biodiversity conservation and governance. A recent example is the establishment of an 88.5 billion RMB national green development fund in 2020 (STIO, 2021).

Although progresses have been made in various fronts for biodiversity in China prior to 2010, there have been some notable challenges as well. For example, China's NBSAP 2011-2030 identified several existing challenges that the country has been facing regarding the improvement of the state of biodiversity as of 2010. These challenges include: incomplete legal and policy system on biodiversity conservation;

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[3] Flora of China - http://www.iplant.cn/frps

[4] Fauna of China - https://species.sciencereading.cn/biology/v/biologicalIndex/122.html

inadequate baseline data on biological resources; significant gap in identifying and cataloguing of biodiversity; lack of monitoring and warning system on biodiversity; in sufficient national investment in biodiversity, which then leads to inadequate management capacity; deficiency in fundamental scientific research supporting biodiversity conservation; low capacity to cope with new challenges facing biodiversity conservation; and lack of awareness of biodiversity conservation across the whole country and society (MEE, 2010).

When assessed again, according to China's Sixth National Report for CBD and based on data by 2018, the main challenges that China has been facing regarding its biodiversity goals include:

- Gaps in the legal and regulatory system, namely in specialized laws and regulations particularly in access and benefit sharing, wetland conservation, and managing invasive species;
- Conflict between socio-economic development and conservation, more prominently around land use in areas with high economic value in relation to conservation efforts (e.g., Protected Areas);
- Inadequate conservation capacities and infrastructure construction particularly to enable the implementation of Protected Areas;
- Shortage of scientific and technical support capacities to establish data collection and monitoring programmes and generate large scale national baseline data for biodiversity (MEE, 2018).

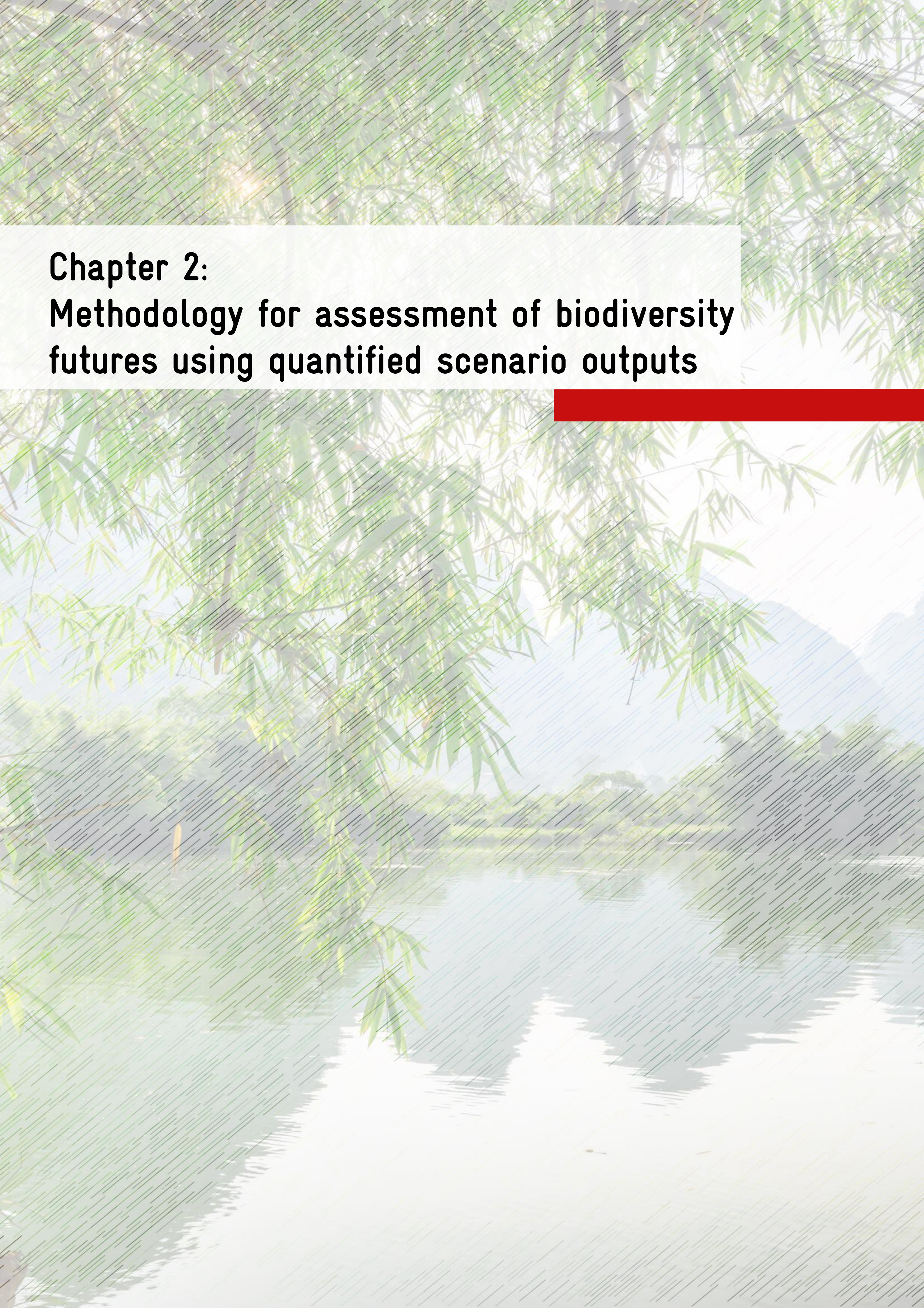
Overall, based on assessment provided in China's Sixth National Report for the CBD, at the national level it is 'on track to achieve target' for 13 out of the 20 Aichi Targets, including those on protected areas, agricultural biodiversity, pollution and resource mobilisation, among others; is 'on track to exceed target' for three of the Aichi Targets, including essential ecosystem services, ecosystem resilience, National Biodiversity Strategy and Action Plan; and is 'progress towards targets but at an insufficient rate' on four of the Aichi Targets, including sustainable fisheries, invasive alien species, vulnerable ecosystems and preventing extinctions (MEE, 2018).

1.6 Links to the modelling framework described in Chapter 2

Our overview of the state of nature in China found that China has an incredibly rich biodiversity that has been threatened by anthropogenic pressures, including land conversion and degradation, caused by China's expanding population and economy. It was such spatially explicit land use pressures that were selected as the focus of our modelling exercise due to the level of impact that such pressures are likely to have on biodiversity in the future, as well as our ability to correlate such pressures with biodiversity responses. In subsequent chapters we explore how land use pressures may change due to 1) the implementation of China's environmental policies (as described in the Master Plan (NDRC and MNR, 2020)), and 2) differing socioeconomic circumstances, and how these changes are likely to impact biodiversity.

Chapter 2:

Methodology for assessment of biodiversity futures using quantified scenario outputs



2 Methodology for assessment of biodiversity futures using quantified scenario outputs

2.1 Summary

We present here a detailed methodology describing the modelling framework developed for this report. This work was designed to analyse the likely consequences to biodiversity of the enactment of China's environmental policies using quantified, spatial outputs.

We first conducted a literature review of policies and selected those that could be quantified using spatial outputs. In brief, these policies centred around the restoration of grasslands and forests and the introduction of protected areas. We designed scenarios where these policies were enacted or not. However, such policies do not work in isolation and their success is dependent upon other socioeconomic drivers.

To account for this, we employed two of the shared socio-economic pathway scenarios – SSP1, a future focussed on sustainable development, and SSP2, a future broadly in line with historic trends (business as usual). These combinations resulted in the exploration of four differing scenarios: SSP1 (baseline), SSP2 (baseline), SSP1 Policy and SSP2 Policy.

Our four scenarios were made spatially explicit through CLUMondo, a land systems model that uses modelled relationships to predict where differing land systems changes are most likely to occur given bioclimatic as well as socio-economic drivers. The land system outputs were then translated to biodiversity and ecosystem service outputs through refinement of pre-existing models. Each scenario was thereby analysed for likely impacts at a national scale on habitat, biodiversity significance, biodiversity intactness and carbon storage. Furthermore, we provide examples of how differing climatic conditions and historical land use may result in differing biodiversity outlooks through focussing on four different regions within China. The results of these assessments are provided in Chapter 3.

This report is primarily aimed at a national scale and with a broad sweep across all biodiversity. However, to illustrate what may be achieved with a narrower focus, we undertook two case studies. The first case study focusses on a specific species, the giant panda, and the second on a specific area, Hainan Island. These case studies are presented in Chapter 4.

2.2 Introduction to our modelling approach

Scenarios are a powerful tool to assess the relationship between specific actions or pathways and the resulting future outcomes. Scenarios can be normative, where the objectives or outcomes are known, and scenario development work focusses on determining the actions or pathways that will arrive at the intended outcome (for example, van Zeijts et al. 2017), or exploratory, where pathways are constructed using plausible actions and events and the scenario development work focusses on the analysis of the alternate futures that these actions produce (for example, Riahi et al. 2017; Rosa et al. 2017). Both types of scenarios are frequently used when constructing and analysing policies. In this study we aim to explore how China's conservation policies are likely to impact future biodiversity and therefore designed exploratory scenarios based upon futures where policies were and were not implemented. However, China's conservation policies are not implemented in isolation. Other aspects of socioeconomic change in China remain dynamic. We therefore accounted for the variability of socioeconomic changes that may plausibly occur using two previously developed scenarios of socioeconomic change (the Shared Socioeconomic Pathway scenarios or SSPs).

Although exploratory scenarios are sometimes a qualitative description of likely actions or futures, we wanted spatially explicit, quantified results to provide a detailed assessment of what impact China's conservation policies could have on biodiversity and ecosystem services, including where that impact might be most felt. Therefore, we translated the conservation policies to quantified land use outputs using a land use model and ran a suite of biodiversity and ecosystem service models against these land use outputs (Figure 1).

In the next sections we provide further details on the methodological process, including how the narrative scenarios were formed (Section 2.3), how the conservation policies were translated into land use outputs by CLUMondo (Section 2.4), and how these outputs were then mapped onto biodiversity and ecosystem models to assess possible biodiversity futures (Section 2.5).

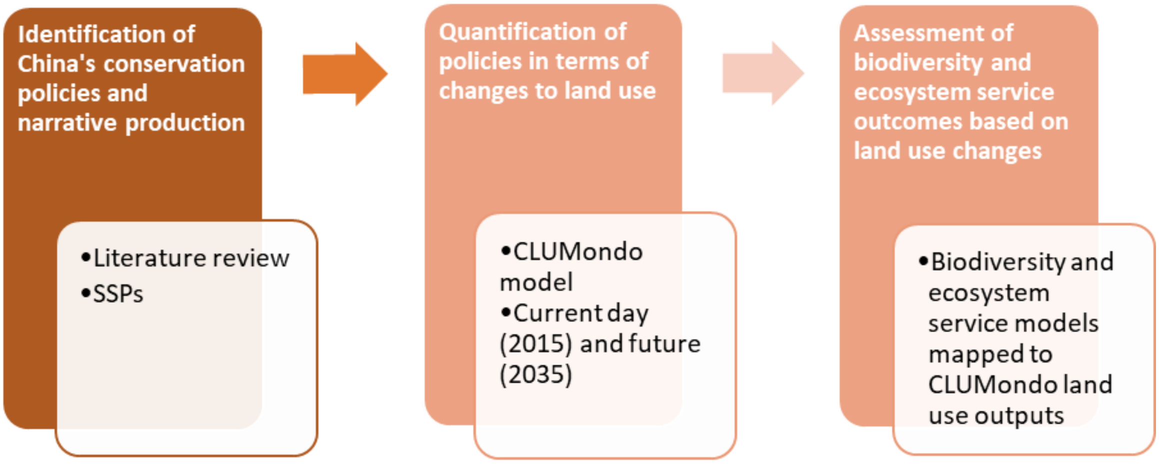


Figure 1. Scenario production process detailing outcomes of process in red and tools and inputs to process in white.

2.3 Scenario production

2.3.1 Description of the SSP scenarios

The Shared Socio-economic Pathways (SSPs) provide a set of plausible alternative futures for global development each having different socio-economic conditions (O'Neill et al., 2014; Popp et al., 2017) (Figure 2). We were therefore able to use these pre-constructed scenarios to capture dynamics of socio-economic change external to the implementation of conservation policies. For this analysis, we focus on SSP1 and SSP2 as these are most compatible with the environmental future in which the conservation targets are set.

Figure 2. The Shared Socio-economic Pathways (SSPs). (Figure from O'Neill et al., 2017)

SSP1 represents a future that is focused on sustainability. In this pathway, land use change and land conversions are mostly controlled: deforestation rates are significantly reduced, crop yield and productivity are increased, food waste is reduced, the growth in meat consumption is slowed, and energy and resource consumption are low. Additionally, investments in education and health are increased and human wellbeing is prioritised over economic growth (Popp et al., 2017; Riahi et al., 2017). SSP2 follows historic patterns in socio-economic and technological trends. Land-use change is moderately regulated, for example, deforestation takes place but at a slower rate than in other SSPs. There is also a slow decline in the rate of crop yield increase, higher food consumption and moderate meat consumption (Popp et al., 2017; Riahi et al., 2017).

The demand data for crops and livestock in China are taken from a previously published analysis carried out using the GLOBIOM integrated assessment model (Zhao et al., 2021). Under SSP1, crop demand in China increases by 5% over 2020 levels by 2030, and then declines to an amount like the demand in 2010 (Figure 3). Under SSP2, demand for crops is projected to continue to rise in the coming decades with production demand peaking at 114% of 2020 levels in 2040 and then declining to 2050. Demand for pig meat makes up the bulk of meat demand in China and is projected to increase by 10% between 2020 and 2030 under the SSP1 scenario and by 14% under SSP2, followed by slow declines in demand to 2050 (Figure 4). Bovine meat is projected to remain almost stable in the SSP1 scenario but to increase 14% from 2020 to 2030 (and 27% to 2050) under SSP2. Demand for sheep and goat meat is projected to increase by 10% to 2030 under SSP1 and then remain nearly constant, whilst SSP2 predicts a growth in demand through to 2050 when demand reaches 132% of 2020 levels (Figure 4).

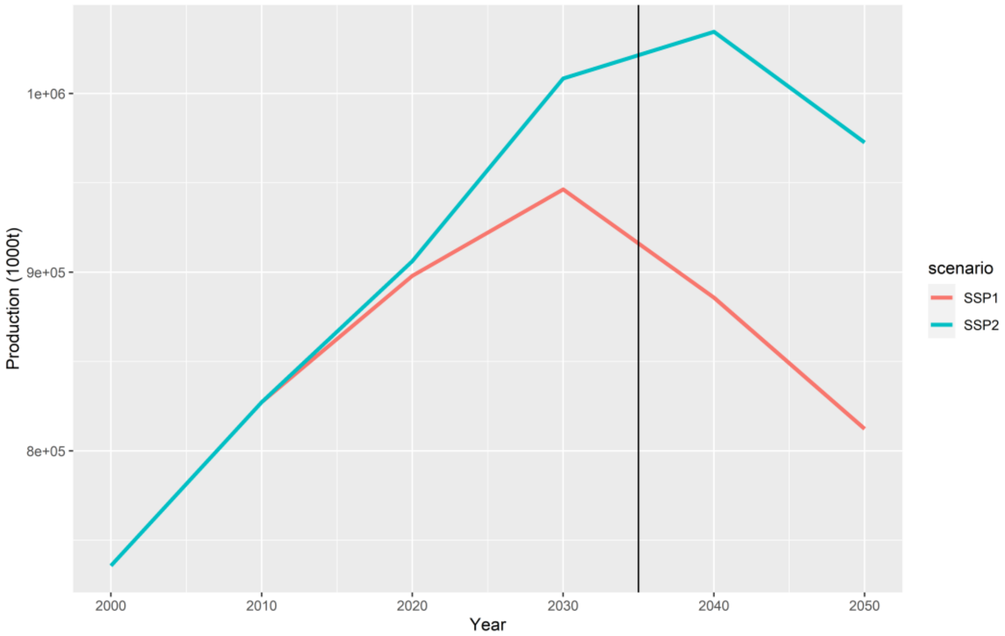


Figure 3. Projections of crop demand in China for SSP1 and SSP2 scenarios (from Hao et al., 2021). The black vertical line indicates the year 2035.

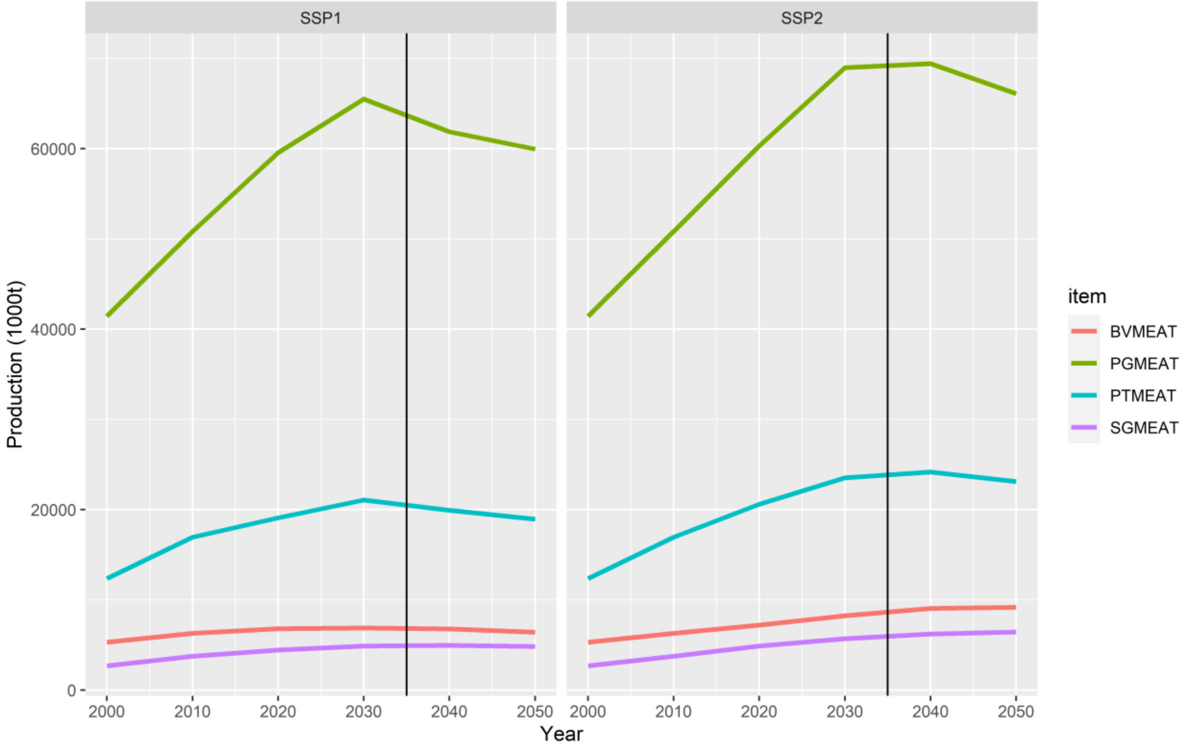


Figure 4. Projections of meat demand in China for SSP1 and SSP2 scenarios (from Hao et al., 2021), where BVMEAT = bovine meat, PGMEAT = pig meat, PTMEAT = poultry meat and SGMEAT = sheep and goat meat. Black vertical line indicates the year 2035.

2.3.2 Selection of policies to include in the scenarios

We reviewed the following policy documents to obtain and collate data on quantitative and qualitative targets to implement within the CLUMondo model: China National Biodiversity Conservation Strategy and Action Plan (MEE, 2010), Sixth National Report for the Convention on Biological Diversity (MEE, 2018), National Master Plan for the Protection and Restoration of Important Ecosystems (2021-2035) (NDRC and MNR, 2020), and The 14th Five-Year Plan for National Economic and Social Development of the People's Republic of China and Outline of the Vision for 2035 (General Office of the Central Committee of the Communist Party of China, General Office of the State Council, 2021b). Table 2 provides the list of goals that were considered.

Table 2. Conservation relevant targets for 2035 described in China's policy documents (NDRC and MNR, 2020).

Goals	2035 target
Forest cover	Increase to 26% of Chinese territory
Forest volume	Increase to 21 billion cubic meters
Natural forest area	Increase to 200 million hectares
Grassland coverage	Increase of comprehensive grassland coverage to 60%
Wetland area	Unchanged
Wetland protection rate	60%
Soil erosion control area	56.4 million square meters
Desertification	>75% of desertified land controlled
Marine ecology deterioration	Reversed
Natural coastline retention rate	35%
Protected area network	>18% of China's land area
Endangered wildlife and habitat	Fully protected

2.3.3 The quantification of scenario narratives

The two baseline SSP scenarios (described in Section 2.1) were refined with the conservation targets (described in Section 2.2) to produce two new scenarios, referred to here as the policy enacted scenarios. The baseline and policy enacted scenarios are summarised and compared in Table 3. The policy enacted scenarios consider goals such as increases in forest cover and natural forests, improvement of grasslands, and erosion reduction. The policy enacted scenarios also have an expanded protected areas network, in which all intensive land uses are prohibited. These scenarios did not include targets for wetlands, marine ecology and natural coastline retention as these realms were not included in the analysis. We chose to focus on the targets of forest cover and natural forest area, and to exclude forest volume to avoid trade-offs between plantation and natural forest.

2.4 The production of land use outputs

2.4.1 Land use model selection process

The conditions that determine land use changes in specific places are complex and result from interactions between socio-economic characteristics, economic drivers and barriers, and biophysical conditions. Land use models are often used to explore potential future scenarios or test policy options, by spatially allocating externally modelled (i.e., through economic models) economic developments throughout the landscape. There are numerous options to model changes to land use.

Qualitative mathematical modelling approaches, such as signed digraph models, allow developers to quickly integrate a range of relationships within coupled socio-ecological systems, especially where data are limited. By capturing the structure of the system, and the types and shapes of responses between components, these approaches can easily allow perturbation (press or pulse) tests to be applied to analyse the impact of different management options, for example development of offshore windfarms (Haraldsson et al. 2020).

Pattern-based models, such as statistical or machine-learning approaches, can be applied to historic observed data to predict future changes in the drivers of environmental change. Sun and Robinson (2018) compare such statistical approaches for modelling land use change.

At the global scale, a range of models are available that can be applied to explore environmental consequences of management options. The IPBES global assessment includes projections from several integrated assessment models including AIM (Asia-Pacific Integrated Model[5]), GLOBIOM (Global Biosphere Management Model[6]), IMAGE (Integrated Model to Assess the Global Environment[7]) and MAgPIE (Model of Agricultural Production and its Impact on the Environment[8]). Some integrated assessment models (IAMs) are run by institutions and remain the property of those institutions while others are available openly, such as MAgPIE. However, all require substantial expertise to use and can require significant amounts of data.

The global nature of these models and their credibility in intergovernmental processes are key assets. However, their generality and resolution can limit their use for certain questions regarding the impact of specific national or local policies. However, both the GLOBIOM (e.g. Zhao et al., 2021) and MAgPIE models are being developed to give a more accurate representation of the Chinese socio-economy.

At China's national scale, models have been developed that describe economic and biophysical aspects of land use. For example, Weng et al (2019) describe a computable general equilibrium model for China and apply this model to understand the impacts of biofuel expansion on land use change and food security. Another model, CLUMondo, has been adapted to describe the future of urban land system in China (Wang et al., 2022).

To assess potential impacts of a range of pressures described in these scenarios on China's national biodiversity, we used a spatially explicit land use model, capable of high-resolution spatial projections that are important for analysing biodiversity impacts. Several such spatially explicit models are available, and all have similar data requirements and outputs (spatially explicit land use maps, that can be opened using geographic information systems (GIS)). The most common land use models (and easiest to set-up) are CLUMondo (van Asselen and Verburg, 2013), LandSHIFT (Schaldach et al., 2011) and Dinamica-EGO (Ferreira et al., 2019).

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[5] AIM Model - https://www-iam.nies.go.jp/aim/
[6] GLOBIOM - https://iiasa.ac.at/web/home/research/GLOBIOM/GLOBIOM.html
[7] IMAGE model - https://models.pbl.nl/image/index.php/IMAGE_framework
[8] MAgPIE model - https://www.pik-potsdam.de/research/projects/activities/land-use-modelling/magpie

Table 3. Societal and environmental goals, spatial limitations and other spatial drivers used to construct the four scenarios (SSP1, SSP2, SSP1 policy, SSP2 policy).

	Baseline scenarios (SSP1 and SSP2)	**2035 policy scenarios (SSP1 policy and SSP2 policy)**
Societal and environmental goals		
Crop production	Following SSP1 and SSP2	Following SSP1 and SSP2
Livestock production	Following SSP1 and SSP2 for grazing livestock	Following SSP1 and SSP2 for grazing livestock
Settlements	Following SSP1 and SSP2 scenarios for population change	Following SSP1 and SSP2 scenarios for population change
Forest cover	No goal	Forest cover increase to 26% of the Chinese territory (from 22.96%)
Natural forest cover	No goal and differentiation between planted or natural forest	Natural forest cover increase to 200 million ha
State of grasslands	No goal	Increase of comprehensive grassland coverage to 60% (from 56%)
Erosion	No goal	Controlling 75% of eroded areas (no grazing or restoration) and no further erosion
Spatial limitations		
Protected area network	Current PA network	Expansion of PA network to cover 18% of mainland China (based on priority areas of Pouzols et al. 2014).
Grazing limitation	Grazing limited to areas with medium and high grassland yield (based on Chinese land use data from 1990-2018)	Grazing limited to areas with medium and high grassland yield and areas outside the newly expanded PA network
Cropland limitation	Cropland limited to non-arid areas	Cropland limited to non-arid areas and areas outside the newly expanded PA network – only low intensity cropland allowed in such areas
Urban expansion	Urban expansion has priority over all other land system processes, but cannot occur on (semi)natural areas	Urban expansion can only occur outside the newly expanded PA network. Existing settlements can intensify or extensify (in terms of population density) in the PA network.
Other spatial drivers		
Climate change	Following the appropriate RCP/SSP combination	Following the appropriate RCP/SSP combination

In this study, we used the CLUMondo model, which can be used to predict future land system changes based on different demands for the services/products which the land provides (Van Asselen & Verburg, 2013). Land systems in the model are defined as landscapes consisting of different shares of cropland, built-up land, grasslands, forests and other land use and land cover. These land systems are combined with information on cropland intensity, livestock density, grassland coverage and population. In this way, the model goes beyond the dominant land use/cover approach, to enable simulating land intensification and extensification in addition to changes in land use and land cover. The CLUMondo model have been applied on different scales throughout China, with examples from Nanning in South China (Nie et al., 2020), Northeast China (Tian et al., 2016), Nanchang in Eastern China (Wang et al., 2020), Jiangsu province (Wang et al., 2019), Inner Mongolia (Liu et al., 2017; Zhu et al., 2020), and across the whole terrestrial territory of mainland China (Wang et al., 2021). CLUMondo is described in more detail in Van Asselen & Verburg (2013), and the Chinese application in Wang et al. (2021). Detailed documentation and the software itself are available at www.environmentalgeography.nl.

2.4.2 CLUMondo model

We built on the CLUMondo model developed for the territory of mainland China by Wang et al. (2021). The purpose of that study was to evaluate land system change due to population dynamics, with particular focus on changes to settlements systems. In this study, however, we were interested in broad scale land system change, due to increased demand for crops and livestock and the implementation of conservation targets. Consequently, we applied considerable changes (Figure 5) to the model of Wang et al. (2021). The changes include modifying the existing 2015 land systems map to account for grazing livestock and eroded areas, protected areas in China, and adding demands for forest cover, natural forest and grassland restoration.

2.4.2.1 Land systems map

The initial land systems map, with a 2x2 km resolution, was developed by Wang et al. (2021) by combining Chinese land use data with data on population density and crop production (see references in Wang et al., 2021). Wang et al.'s map was updated to account for grazing, natural grassland and eroded areas and simplified the settlement systems classification.

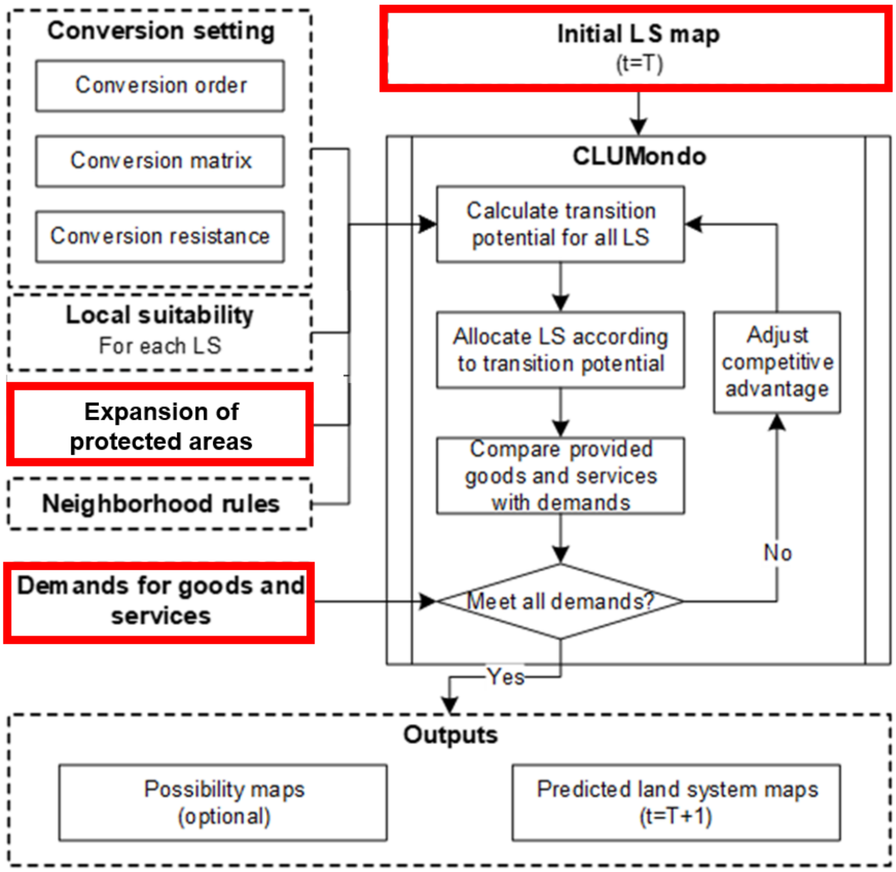

Figure 5. Outline of CLUMondo model. Parts marked with red represent modifications to the Wang et al. (2021) model as described

This preparation process entails the following steps:

Firstly, the settlement systems were aggregated to four main systems: high dense urban, low dense urban, peri-urban and suburban. These systems differ in terms of the population density, and presence of cropland and livestock. For example, suburban areas host considerable cropland and livestock activities as opposed to high dense urban areas.

Secondly, the land systems map was overlaid with the only accessible spatial distribution data on livestock grazing (Robinson et al., 2014). Goat and sheep densities were used to identify grazing systems of different densities (high, medium and low), and grassland systems without livestock presence (classified as natural grasslands). We did not use cattle density in our classification, as most of the cattle (estimated 96.4%) are landless and are defined as industrial or urban livestock systems. On the other hand, a considerable share of goats and sheep (30%) are still grazing (Zhao et al., 2021).

Finally, degraded grazing areas were identified, as one of the Chinese 2035 policy targets stipulates restoration of these areas. We used the spatial distribution of eroded areas in China from the Resource Environmental Science and Data Centre of the Chinese Academy of Sciences, which is the only accessible (and empirically derived) dataset on soil erosion for China. We overlaid the areas with above-moderate erosion with grassland areas to identify eroded grasslands and classified them as eroded grazing areas. Comparison with the livestock density map showed that these areas are indeed being grazed, with an average density of 25 goats and sheep combined per km^2. While overlaying our land system map with the erosion map does present some uncertainty, we also compared the estimated identified eroded areas with estimates from the literature. Our overlay suggests, that 16% of grazing areas are eroded, with a study on grassland degradation identifying that 23% of Chinese grasslands are eroded (Zhou et al., 2017).

2.4.2.2 Spatial probability

As is standard in the preparation of a CLUMondo model, and like the approach of Wang et al. (2021), we looked at the relationship between socio-economic and biophysical factors to understand the likely spatial distribution of land use changes.

Table 4. Explanatory variables and data sources for the socio-economic and climate and biophysical categories used in the logistic regression model.

Explanatory variable	Original resolution and temporal coverage (unit)	Description	Source
Socio-economic			
Accessibility	≈1 km, 2015	Distance to cities	(Weiss et al., 2018)
Climate and biophysical			
Precipitation	1 km, 2000-2100, (mm)	Annual precipitation (sum of monthly means)	(Fick and Hijmans, 2017)
Temperature	1 km, 2000-2100, (°C)	Annual temperature (sum of monthly means)	(Fick and Hijmans, 2017)
Slope	90m, (degree)	Calculated from SRTM	(USGS, 2012)
Altitude (SRTM)	90m, (m)	Median elevation of cell	(USGS, 2012)
Sand content	1 km, 2010, (%)	Sand mass in %	(Stoorvogel et al., 2016)
Clay content	1 km, 2010, (%)	Clay mass in %	(Stoorvogel et al., 2016)
Soil water capacity	1 km, 2010, (100 cm^3/ cm^3)	Soil water holding capacity	(Stoorvogel et al., 2016)
Organic carbon content	1 km, 2010, (g / kg)	Grams of organic content in kg of soil	(Stoorvogel et al., 2016)
pH	1 km, 2010, log(h+)	log(h+)	(Hengl et al., 2014)

To do this we performed logistic regression with ten socio-economic and biophysical factors as explanatory variables (Table 4). We chose the ten explanatory variables based on earlier studies showing the most important variables underlying different types of land use changes (Bürgi et al., 2005; van Asselen and Verburg, 2012). All input data was first resampled to match the spatial resolution of the land system map. We then analysed explanatory variables for cross-correlation to remove variables with correlation >0.8 ensuring that no model would include both variables. All factors included in our model are significant at p<0.01.

Table 5. Land systems contributions in terms of population, built up area, crop production, crop extent. goats and sheep, tree cover and grassland, for each broad system class (Wang et al., 2021).

Description	Population (nr/km^2)	Built up area (km^2/cell)	Crop production (tons/cell)	Crop extent (km^2/cell)	Goat and sheep (nr/km^2)	Tree cover (km^2/cell)	Grassland (km^2/cell)
Settlement systems							
High dense urban area	40.80	2.89	175.31	0.51	38.28	0.11	0.02
Low dense urban area	7.87	2.7	367.93	0.91	53.19	0.11	0.04
Peri-urban area	15.80	1.27	568.10	1.50	42.30	0.30	0.09
Sub-urban area	3.55	1.26	779.07	1.99	61.54	0.30	0.12
Cropland systems							
Agricultural villages	3.20	0.1	1,143.53	2.94	60.87	0.38	0.15
High-intensity agriculture	0.60	0.01	1,292.54	2.29	53.59	1.14	0.21
Med-intensity agriculture	0.43	0	564.25	1.89	43.55	1.35	0.54
Low-intensity agriculture	0.26	0	216.58	1.49	42.38	1.25	0.99
Grazing systems							
Non-degraded grazing low	0.15	0	0	0	8.76	0	2.90
Non-degraded grazing medium	0.15	0	0	0	30.75	0	2.90
Non-degraded grazing high	0.15	0	0	0	84.77	0	2.90
Degraded grazing	0.15	0	0	0	25.39	0	2.90
Grass-forest mix system	0.04	0	0.00	0.02	27.76	1.97	1.79
Forest and natural systems							
Natural grassland	0.04	0	0	0.02	0	0	2.90
Natural forest	0.03	0	0	0.02	0	3.61	0.02
Planted forest	0.03	0	0	0	0	3.61	0.02
Other systems							
Wetland	0.15	0	0	0	0	0	0.01
Water	0	0	0	0	0	0	0.01
Other land	0.01	0	0	0	0	0	0.01

2.4.2.3 Land system contributions and demands for goods and services

Wang et al. (2021) combined the initial land systems map with a population density map and crop production statistics, to derive the contribution of each land system in terms of population and crop production. We updated this approach by combining the land systems map with the density of goats and sheep (Robinson et al., 2014), tree cover (Hansen et al., 2013) and grassland coverage (obtained from a Chinese land use map[9]). This enabled us to quantify each land system's contributions (Table 5) to different societal and environmental demands. These contributions were used in the future land use modelling, where we simulated land systems change under the different scenarios for population dynamics, crop and livestock production, tree cover, and grassland coverage.

2.4.2.4 Conversion rules and spatial restrictions

Before modelling we had to specify which conversions would be allowed in the model. While some conversion limitations are obvious – high-density urban areas cannot convert to cropland – others are based on iterations together with Chinese experts on land use and the scenario logic. For example, conversions to high intensity grazing are only allowed in areas with sufficient grassland yield (based on the distribution of high yield grassland between 1990-2018 using the Chinese land use map[10]). Additionally, we excluded protected areas from conversions by using publicly accessible data on protected areas (UNEP-WCMC 2020) for all scenario runs. For the policy target scenarios, we expanded the protected area network using data on prioritizing future areas for nature protection (Pouzols et al., 2014), where we identified the top 18% of areas for future protection (following the Chinese national targets). In these areas only certain conversions were allowed: conversions to more natural land systems (natural grasslands, forests), or decreases in the intensity of use (e.g., high intensity cropland or grazing to low intensity cropland or grazing).

It should be noted that our methodology provides an approach to spatially identify the areas where a more in-depth and local scale processes will be required to address and resolve key land-use challenges between social, economic and biodiversity-related objectives. Further work will be required in order to incorporate social data, including the values and needs of indigenous peoples and local communities. These iterations of the methodology might be most practical at a sub-national scale, and in combination with multi-stakeholder engagement and dialogue.

2.4.2.5 Data limitations

The primary spatial data used in the production of the current day (2015) land systems layer by the CLUMondo model (Table 6) are remotely sensed observations of land cover and use in China from the Chinese Academy of Sciences[11].

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[9] China Multi-period Land Use Land Cover Remote Sensing Monitoring Dataset (CNLUCC) - https://www.resdc.cn/DOI/DOI.aspx?DOIid=54

[10] China Multi-period Land Use Land Cover Remote Sensing Monitoring Dataset (CNLUCC) - https://www.resdc.cn/DOI/DOI.aspx?DOIid=54

[11] China Multi-period Land Use Land Cover Remote Sensing Monitoring Dataset (CNLUCC) - https://www.resdc.cn/DOI/DOI.aspx?DOIid=54

Table 6. The primary spatial data used in the production of the current day (2015) land systems layer by the CLUMondo model

Data	Description/comments	Source
Land use/cover, land intensity		
Land system maps	Land systems map for China	(Wang et al., 2021)
Planted forest	Global spatial distribution of planted forests (the remaining forests were considered as natural)	(Schulze et al., 2019)
Livestock grazing	Livestock density maps	(Robinson et al., 2014)
Land use data	Identified areas with medium and high grassland yield from 1990-2010 land use/cover data	(Chinese Academy of Sciences, Xu Xinliang et al., 2018)
Environmental characteristics		
Soil erosion	Spatial distribution of different types of soil erosion in China	(Xu Xinliang, 2018)
Environmental policies		
Protected areas network	Current and future protected areas. Future areas identified as top 18% priority areas as stipulated in the policy	(Montesino Pouzols et al., 2014)

The baseline also includes spatial data on the location of international protected areas, such as those designated as World Heritage Sites, UNESCO Man and Biosphere reserves or Ramsar Sites of International Importance.

The scenario modelling does not include trends in marine, wetland or freshwater ecosystems, focussing instead on changes to terrestrial land use and implications for terrestrial biodiversity. In addition, it does not include information on nationally designated protected areas (data is not internationally available), species level conservation activities or invasive alien species.

2.5 Biodiversity and ecosystem service models

Previous sections outlined how we produced scenarios and spatially explicit layers of land use change for each scenario. Using these spatially explicit layers, we used a suite of biodiversity and ecosystem service models to assess biodiversity futures.

We selected biodiversity and ecosystem service models to account for differing aspects of biodiversity. In brief, the indicators selected to assess differing biodiversity futures were:

- **Biodiversity significance**
  This indicator measures the significance of an area based upon 1) the number of species present

and 2) how important that area is to each species in terms of the proportion of its global range is found within that area.

- **Biodiversity intactness**
  This indicator measures how the make-up of species communities, in terms of the relative abundance of species within a community, has been altered through human pressures.
- **Connectivity**
  This indicator measures the degree that areas of habitat are interconnected with the assumption that an increase in the connectivity of suitable habitat will be beneficial to the success of populations in the area. Within our analyses, we investigate connectivity of habitat for giant pandas as well as forest dependent species.
- **Carbon stocks**
  This indicator measures the ecosystem service of carbon sequestration associated with forested areas.

2.5.1 Biodiversity significance

One approach to understanding potential impacts of different future scenarios on biodiversity is to measure changes from habitat loss or degradation within the distribution of species (Brooks et al. 2019). Metrics based on species range data have the benefit of highlighting areas where risks to individual species from habitat loss are high. As well as providing spatially explicit outputs, impacts can also be quantified for individual species or groups of species. There are numerous metrics based around this (Buchanan et al., 2011; Hill and Arnell et al., 2019; Duran et al., 2020), each relying on linking habitat preferences to land use/land cover and measuring changes in the area of habitat (AOH) of the species (Brooks et al., 2019). In this project, the biodiversity significance of an area is based on the number of species present in the area as well as the importance of that area in terms of a species' total geographic range. The metric is adapted from the biodiversity importance score by van Soesbergen et al. (2017), but here we use the term biodiversity significance to be consistent with more recent analyses, such as Hill et al. (2019).

2.5.1.1 Model methodology

We assessed changes in biodiversity significance resulting from land use changes using a metric based on species' area of habitat (AOH). We used species range and habitat affiliation data from the IUCN Red List (IUCN, 2021) as it has comprehensively assessed three terrestrial vertebrate classes, (birds, amphibians and mammals), within the study region. We excluded species in the Least Concern (LC) category, to focus on species that were threatened (i.e., Critically Endangered, Endangered or Vulnerable), Near Threatened (NT), or Data Deficient (DD) as habitat changes for these are typically of more immediate conservation concern.

The study region was based on the extent of the CLUMondo data and split into 10km x 10km grid cells, which the main unit of analysis. We defined suitable habitats for individual species using a crosswalk table (Table 7) between CLUMondo land use types and IUCN habitat classes, based on expert opinion (CLUMondo and modellers at UNEP-WCMC) and areas from Table 3. Where an IUCN habitat was only partially represented by a land use class (e.g., Forest habitat in the "Grass-forest mix system" land use class), we applied a weighting based on the proportion of habitat in that land use (where this was known). We defined the AOH for a given grid cell and species, as the total area of habitat in that cell (i.e., land use data), multiplied by the proportion of the cell covered by the species' range. This proportional overlap approach helps account for some of the spatial uncertainty in the underlying range data and the land use models. The biodiversity metric of a grid cell for a species is the area of habitat in that cell, divided by the area of habitat in all cells. This figure is then multiplied by the ratio of the area of overlap of the species range with the study region, to its total (global) range. Applying this weighting aims to account for the range of the species outside the study area, thus giving a higher weighting to species with a small range. The individual species scores are then summed over all species to obtain a total biodiversity value. Changes in the biodiversity significance due to land use changes were assessed for each species and grid cell, relative to the baseline (i.e., 2015). For species with multiple seasonal ranges (e.g., resident, breeding, non-breeding), we analysed and mapped each season separately as a given species may have significant proportions of the population in the area at one time. For such species, typically birds, we plotted graphs based on the seasonal range most negatively impacted, as this has the most immediate conservation relevance.

2.5.1.2 Assumptions

Our methodology makes several assumptions. Firstly, within a given grid cell, the species range and the land use data are spread uniformly. When the species range and its habitat only partially cover a grid cell, we assume that land use changes anywhere within the cell will have an effect.

We also assume that within the AOH of a species its population is distributed equally. In the real world this is not the case, resulting in a lower confidence in the assessment of the significance of an area to a species. However, when looking at the broad patterns, as opposed to an individual species, the uncertainty is lower.

Furthermore, we assume for the sake of this analysis that the area of suitable habitat is the only factor influencing a species' ability to persist, thus factors such as hunting, habitat fragmentation and climate related range shifts are not included in our assessment of a refined species' range. Especially in higher threat categories, such additional threats on top of habitat loss may lead to extirpation or extinction.

Lastly, the impacts from AOH changes over time are only considered for the study area. Thus, if natural habitat continues to decline in the wider world, species not restricted to China (i.e., non-endemics), will typically have more negative outcomes than shown in this analysis.

Table 7. Crosswalk between IUCN Habitats and CLUMondo land use classes based on expert opinions. Linkages in the table are shown as weighted values. Values less than 1 are based on the proportions of habitat estimated to be in that land system (See Table 3).

IUCN Habitat Description and code		High dense urban area 0	Low dense urban area 1	Peri-urban area 2	Sub-urban area 3	agricultural villages 4	High-intensity agricultural system 5	Med-intensity agricultural system 6	Low-intensity agricultural system 7	Non-degraded grazing low 8	Degraded grazing 9	natural grassland 10	Grass-forest mix system 11	natural forest 12	planted forest 13	Wetland 14	Water 15	Other land 16	non-degraded grazing medium 17	non-degraded grazing high 18
1	Forest												0.49	1						
2	Savanna											1								
3	Shrubland									0.28	0.28	0.28	0.06	0.09	0.09				0.28	0.28
4	Native Grassland											1								
5	Wetlands (inland)															1	1			
6	Rocky Areas																	1		
8	Desert																	1		
14.1	Arable Land	0.13	0.23	0.38	0.5	0.74	0.57	0.46	0.37				0.01	0.01	0.01					
14.2	Pastureland						0.05	0.14	0.25	1	1		0.45						1	1
14.3	Plantations														1					
14.4	Rural Gardens			0.38	0.5				0.37											
14.5	Urban Areas	1	1	1	1	0.03														
14.6	Subtropical/Tropical Heavily Degraded Former Forest	0.03	0.03	0.08	0.08	0.08	0.3	0.34	0.31						1					
15	Artificial – Aquatic																1			
16	Introduced Vegetation														1					

2.5.2 Biodiversity intactness

The Biodiversity Intactness Index (BII) measures the relative changes in abundance of species within a local species community thus providing a measure of how the make-up of species communities are changing (Scholes and Biggs (2005). The concept of the BII was first introduced by Scholes and Biggs (2005) and later refined by Newbold et al. (2015). The BII provides a measure of the naturalness of an area's biodiversity compared to a pristine condition.

Biodiversity intactness was modelled using data from the PREDICTS (Predicting the Responses of Ecological Diversity in Changing Terrestrial Systems) database (Hudson et al., 2017), a large global biodiversity database that collects data on species' responses to anthropogenic pressures. It hosts information on the abundance and occurrence of species within assemblages under differing levels of anthropogenic pressures such as land uses, land-use intensities, levels of fragmentation and other drivers (Hudson et al., 2017). The PREDICTS database is taxonomically diverse, with approximately representative samples of vertebrates, invertebrates, plants and fungi. PREDICTS has a hierarchical structure of comparable samples of biodiversity from multiple sites, each study site having an assigned land use according to a standardised classification table (Newbold et al., 2016).

2.5.2.1 Model methodology

We used mixed effects models to quantify estimates of how anthropogenic pressures have impacted BII. Mixed effects models are well suited for such analyses as they can deal well with missing data points, as is common with observational data, as well as data that is nested or hierarchical (Harrison et al., 2018; Zuur et al., 2009). In the case of PREDICTS, the database has a hierarchical structure in that data sources contain one or more studies of one or more geographic blocks of study sites (Newbold et al., 2016). As such, we might expect that measurements within a study might be more similar than measurements from different studies. Furthermore, each study in the PREDICTS database has its own taxonomic focus, geographic area, sampling method, and sampling effort.

To prepare the dataset for model production we first reduced the global database to include only data for biomes present in China. This resulted in approximately 600 studies across 23,000 sites including over 3 million observations.

We then assigned land system classes, as used by CLUMondo, to sites within the PREDICTS database. The PREDICTS database contains several fields of land use descriptors, assigned using information provided the collectors of the biodiversity samples, including predominant habitat, land use intensity, crops in production, livestock density, type of farming (for instance, certification scheme), and data on the surrounding land use matrix. The database also contains free text fields describing land use. The primary sources for our land system classification were the predominant habitat and land use intensity fields (Table 8).

Table 8. Classification of CLUMondo land system classes using PREDICTS habitat and use intensity classes. Where CLUMondo classes have been joined this is indicated using a "/". *these land system classes are only present in scenarios.

PREDICTS habitat	PREDICTS use intensity	CLUMondo land system
Primary non-forest		
	Minimal	Natural grassland / natural forest
	Light	Grass and forest mixed system
	Intense	Grass and forest mixed system
Primary forest		
	Minimal	Natural grassland / natural forest
	Light	Grass and forest mixed system
	Intense	Grass and forest mixed system
Mature secondary		
	Minimal	Natural grassland / natural forest
Young secondary		
	(all)	Restored grassland / restored forest / restored grass and forest mixed*
Plantation forest		
	(all)	Planted forest
Cropland		
	Minimal	Low intensity agricultural system
	Light	Sub-urban area / Medium intensity agricultural system
	Intense	Agricultural village / High intensity agricultural system
Rangelands		
	Minimal	Nondegraded grazing low intensity
	Light	Nondegraded grazing medium intensity
Managed pasture		
	Light	Nondegraded grazing high intensity
	Intense	Degraded grazing
Urban		
	Minimal	Peri-urban area
	Light	Low dense urban area
	Intense	High dense urban area

The final model structure was selected using backwards stepwise selection using akaike information criterion (AIC) values (Zuur et al. 2009). Two models were produced – one model estimating the impact of human pressures on total community abundance, and the other estimating the impact of human pressures on community compositional similarity. The product of these models produces the BII (Newbold et al. 2015). Random effects included in the selection process were source identity, study identity and the blocking structure for both models. Fixed effects included in the abundance model were land system, human population density, and road density. We derived historical human population density by downsampling the HYDE3.1 dataset (Goldewijk, 2011). Road density was obtained from the Global Roads Inventory Project database (Meijer et al., 2018). Fixed effects included in the compositional model were geographic distance, environmental distance, and the pairwise contrast of land uses. For full details of predictor variables, including datasets used, see Hill et al. (2019).

The modelled pressure/response relationships were then projected onto the baseline and scenario data layers to form the spatial layers of BII. Land system maps were output from the scenarios. Areas of restoration were calculated by comparison of baseline and future scenarios and these areas were assumed to be equivalent to young secondary vegetation. Road density was assumed to stay constant throughout the scenarios. Projected human population data was derived from the Spatial Population Scenarios (SPS), which match the SSPs and take into account urbanization (Jones, 2016).

2.5.2.2 Assumptions

The BII methodological approach makes a number of assumptions. We assume that the pressure-response relationships estimated in the models are constant throughout time and space. For example, the biodiversity difference between a primary forest and a plantation (modelled from current day survey data) is assumed to be the same when a primary forest is converted to plantation forest in the future. This assumption is known as a space-for-time substitution. Our methodology also assumes that biodiversity differences among nearby sites are driven by the variables in the models, but other pressures are likely to be faced by the organisms sampled that are not included in the models such as climate change, invasive species and hunting pressures. Finally, our methodology assumes that any forest or grassland restoration projected in the scenarios undergoes passive restoration without interventions to speed up the rate of succession.

2.5.3 Connectivity

Landscape connectivity is the degree to which the landscape facilitates or impedes the movement of species among available habitats (Saura et al., 2011). There are various methods for analysing the connectivity between different patches of habitat. There are also numerous indices for combining distances between patches into an overall connectivity score for the landscape. These include using straight line distance between habitat patches or using more ecologically relevant cost-weighted distances which consider the land cover between patches. Cost-weighted distance approaches typically consider the different types of land cover between patches, considering that natural vegetation is easier to move through (provides less “resistance”) than e.g. agriculture and urban areas.

2.5.3.1 Model methodology

For this analysis we use indices based on the probability of connectivity (PC). PC is the likelihood that two animals randomly placed in the landscape can reach each other, given a set of habitat patches and direct links among patches (Saura and Pascual-Hortal, 2007). We calculate habitat patch contributions to the overall landscape connectivity, as well as the landscape connectivity between different scenarios. For habitat patch level connectivity, we use the dPC index. This shows the change in PC for the landscape when a given patch is removed. It is calculated by iteratively removing patches and measuring the changes in PC for the landscape, and therefore shows the contribution of each patch to the network's connectivity.

To compare the connectivity changes in a landscape between scenarios, we use a modification of the PC index called the equivalent connected area (ECA) (Saura et al., 2011). ECA is defined as the size of a single habitat patch that would provide the same value of the probability of connectivity than the actual habitat pattern in the landscape (Saura et al., 2011). ECA has the advantage, over PC, of having the units as area (rather than a probability), making it more straightforward to interpret when comparing changes in habitat area. The change in ECA is compared with the change in habitat area, between each scenario and the baseline. This highlights whether the loss/gain of habitat is having a disproportionally large impact on the equivalent connected area.

The PC and ECA indices consider species' dispersal abilities. This dispersal distances can either be for a specific species or a group of generic species, such as species with short or long dispersal abilities.

We use cost-weighted distances between habitat patches, given its higher ecological relevance. This is based on a resistance layer produced for each analysis and scenario. All PC and ECA calculations were undertaken in Conefor 2.6[12]. Cost-weighted distances were produced using Linkage Mapper (McRae and Kavanagh, 2011).

We undertook two separate connectivity analyses; the first study focussed on how changes in connectivity may influence giant panda habitat, and the second study focussed on how reforestation on the island of Hainan may influence forest connectivity. Giant pandas were chosen as they are an icon of conservation efforts in China. Even though these conservation efforts are increasing the numbers of giant pandas, they are still endangered with the lack of connectivity between habitat being a large issue. Hainan Island was chosen as it is extremely biodiverse in forest specialist species and has experience a large decline in forest cover over the last two centuries.

2.5.3.2 Giant panda

Connectivity within the giant panda's (*Ailuropoda melanoleuca*) landscape, and between each habitat patch, was calculated using least-cost paths. Least-cost paths are the shortest distances between each habitat patch, considering the resistance in the landscape (cost-weighted distance). The landcover data for each scenario and the baseline was reclassified into a binary habitat and non-habitat layer. The natural forest and grass-forest mix system categories were classified as suitable habitat and the remaining categories as unsuitable habitat. The habitat cells within the panda's range (excluding IUCN presence code 3: Possibly Extant) were extracted using the IUCN giant panda distribution range (Swaisgood, R., Wang, D. & Wei, 2016) for each layer. These were then converted into polygon layers and were used as the habitat patches for the analysis.

To produce the resistance layer, a buffer of 50 km around a convex hull encompassing the panda's IUCN range was created (the distance chosen represents more than the maximum dispersal distance used). This polygon was then used to extract the cells from the baseline and scenario landcover layers. The resulting rasters were then reclassified with the habitat categories (natural forest and grass-forest mix system) having a value of 1 and everything else a value of 100. Values of 1 for natural habitat and 100 for barriers is recommended (McRae and Kavanagh, 2011).

There is limited knowledge on panda dispersal abilities and their response to barriers (and what these barriers are) (Bu et al., 2021). As pandas are habitat specialists and there is little evidence that they use other habitat types (Bu et al., 2021), we assume other habitat types are barriers for their dispersal. Bu et al

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[12] Conefor - http://www.conefor.org/index.html

(2021) showed that even plantation forests were not suitable for providing connectivity between core habitat patches. Large rivers are also barriers to species dispersal and so these were also included as a value of 100, using data from HydroRIVERS (Lehner and Grill, 2013). Larger rivers were selected using flow categories 1-4, and then turned into a raster matching the resolution of the landcover data. Finally, elevations outside of the panda's upper elevation limit (4100m), obtained from the IUCN Red List (Swaisgood et al., 2016), were added as barriers. The lower elevation limit (1200m) stated in the IUCN Red List was not used as a barrier as panda's have been recorded in elevations lower than this (e.g., Zhang et al., 2014).

Connor et al. (2016) summarise research on panda dispersal. The maximum dispersal distance recorded in the studies they summarise is 34 km. This figure of 34 km agrees with calculations by Santini, L., (pers. comm., July 2015) based on an allometric model (Santini., 2013) using data on body size, home range (Jones et al., 2009) and diet (Price et al., 2012). Therefore, we use this as our dispersal distance with a probability of 0.05. We also tested other maximum dispersal distances (10 km and 20 km higher and lower) confirming this parameter has minimal impact on the results, with the overall picture being the same.

Giant pandas are dependent on the presence of bamboo species within forested habitats for their food. As there is a lack of data on bamboo distribution, we assume that all forested areas represent suitable habitat for giant pandas. However, this will lead to overestimates of both our extent and connectivity results. Likewise, due to a lack of data on what habitats giant pandas can move through, we make assumptions that they can move through forest land use types, with other land uses acting as barriers. Finally, as the landcover scenarios data are coarse ($2km^2$), the models assume that within each $2km^2$ cell the connectivity resistance is constant. There are likely to be features within cells that also affect connectivity.

2.5.3.3 Hainan Island

Connectivity of forest in Hainan as a whole, and between each habitat patch, was calculated using least-cost paths. The landcover data for each scenario and the baseline was reclassified into a habitat and non-habitat binary layer. The natural forest and grass-forest mix system categories were classified as habitat and the remaining categories as non-habitat. These were then converted into polygon layers and were used as the habitat patches for the analysis.

Two resistance layers were produced for each scenario to represent generalist and specialist forest species. For the generalist species resistance layer, only the urban land use categories (0-4) and water (15) were classified as barriers (with a value of 100), with all other categories considered as being easy for the species to move through (a value of 1). The specialist forest species resistance layer had the same value for urban and water barriers, but the only categories considered as easy for species to move through were natural forest and grass-forest mix system (11 and 12). All other land use categories were given a value of 10 (i.e., 10 times more difficult to move through than forest) apart from planted forest which was given a value of 5. Large rivers were also included as barriers to species dispersal in both versions, with a value of 100, using data from HydroRIVERS (Lehner and Grill, 2013). Larger rivers were selected using flow categories 1-4, and then turned into a raster matching the resolution of the landcover data.

Similar studies in South-East Asian forests use median dispersal distances of 100m, 1km and 10km (Wang et al., 2021, 2016). However, the resolution of our data does not allow for the 100m and 1km distances. Therefore, we use median dispersal distances of 5km, 10km and 25km, similarly used in forest elsewhere (Saura et al., 2011), and acknowledge that species with short dispersal distances are not captured in our analysis.

2.5.4 Carbon change

Obtaining an understanding of the ecosystem services that nature provides is an important aspect when examining spatially explicit outcomes of policy scenarios. Assessing changes to carbon sequestration within future scenarios, in particular, can help with understanding how policy can be targeted to mitigate environmental impacts (Zhang et al. 2020). Here we quantify the carbon stock available from trees and grasslands in each biome and the gains/losses that would take place per biome under the different SSP scenarios.

2.5.4.1 Methodology

The carbon stock availability from vegetation per 2x2 km^2 grid cell was computed separately for trees and grasslands.

For trees, we mapped data from the Global Ecological Zones (GEZ) (FAO 2012) with the land system classes for each scenario. We defined the forest status or condition (IPCC 2019) for each land system class in the following way:

- trees in natural forests and grass-forest mix system were considered *primary forests*
- trees in areas with new natural forests and grass-forest mix systems were considered *secondary <20 years*
- trees in planted forests were considered *planted secondary > 20 years*
- trees in all other land system classes were considered *secondary > 20 years*

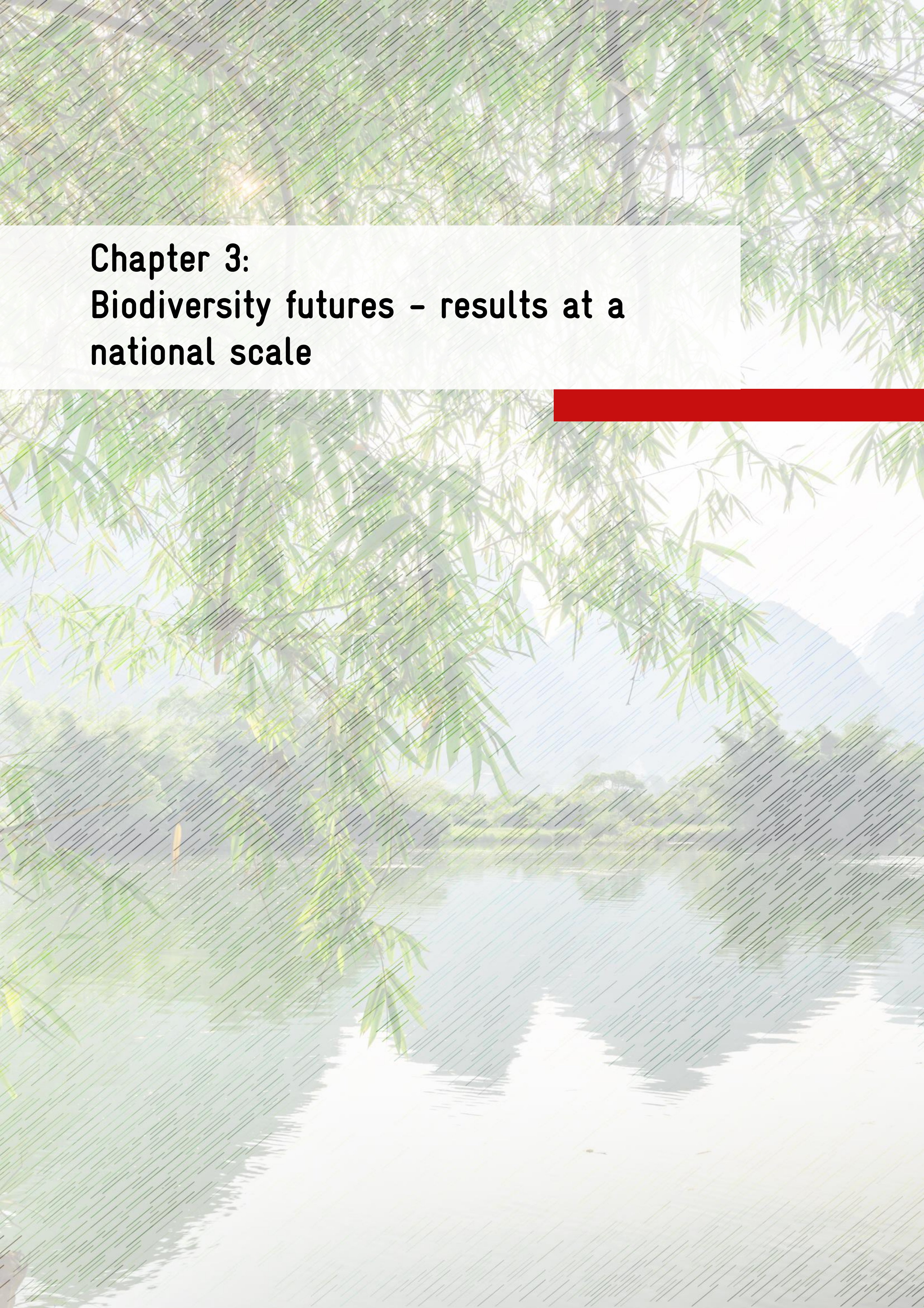
With this knowledge, we prepared a crosswalk table (available upon request) of carbon stock for every combination of land system type, GEZ and forest status or condition. The above ground biomass and ratio of below-ground biomass to above-ground biomass values for different trees and grasses (based on the GEZ and IPCC climate zone respectively) were obtained from IPCC reports (IPCC 2006; IPCC 2019). These were used to compute the carbon stock densities. We then computed the total carbon stock per grid cell based on the area of trees in each land system type.

For grasslands, we overlayed data from the IPCC Climate zones (Harris et al. 2014; Karger et al. 2017; Karger et al. 2018) with the land system classes for different scenarios. We then prepared a crosswalk table of carbon stock for every combination of land system type and IPCC climate zone. Following this, we calculated the carbon stock per grid cell based on the area of grassland in in each land system type. Finally, we combined the carbon stock layers for trees and grasslands and computed statistics per biome.

2.5.4.2 Assumptions

Our methodology makes several assumptions. Firstly, we assume that all trees in areas designated planted forests in both 2015 and 2035 were planted prior to 2015. Likewise, in 2015, all areas designated as secondary were assumed to be composed of mature trees (over 20 years old). Finally, we assumed that the spatial areas of all biomes stayed constant over time.

Chapter 3:
Biodiversity futures – results at a national scale



3 Biodiversity futures – results at a national scale

3.1 Summary

In this chapter we present biodiversity outlooks for the four different futures described by our scenarios. Our scenarios estimate likely futures based on two differing global socio-economic situations – encoded by SSP1 and SSP2 – with Chinese environmental policies (including increase of natural forests and grasslands and expansion of the protected area network, see Table 3) enacted or not. This allows us to explore the impact of the policies taking into account the uncertainty around differing direct and indirect socio-economic drivers.

Our scenarios estimate starkly different futures. The SSP2 baseline scenario (i.e., the SSP2 scenario without policy enacted) tends to be the least favourable of the four scenarios across our measures of biodiversity impact with losses forecast in forest and grassland driving overall decreases in species range sizes, biodiversity significance, and biodiversity intactness, as well as losses in ecosystem services including large losses in carbon stocks. However, SSP2 Policy shows that China's environmental policies are likely to be effective at reversing these trends with biodiversity recovery estimated to occur within restored areas.

A comparison of the baseline scenarios, SSP1 and SSP2, reveal the impacts that a change to the sustainable development and socio-economic drivers encoded in SSP1 will make. As demand for agricultural and urban land is lower in SSP1 than SSP2, agricultural intensification and urbanisation is reduced, resulting in lower degradation of biodiversity in working landscapes.

The future described by the SSP1 Policy scenario provides the most positive biodiversity results when compared across all scenarios. This combination of the sustainable development (encoded by SSP1) and the enactment of China's environmental policies results in the widespread restoration of biodiversity whilst achieving an increase in production to support China's future population.

The IPBES task force on scenarios and models has recently developed a framework to help to explore the consequences of prioritising different values of nature, including nature for society, nature as culture and nature for nature (Pereira et al., 2020). These differing values can then be incorporated into scenarios such as the SSPs. The work presented here does not directly explore the production of new scenarios along these lines, but the indicators of change that we estimate do align with the differing aspects of the nature futures framework. For instance, changes to biodiversity significance indicate what might happen to nature for nature, changes to carbon stocks indicate what might happen to nature for society, and changes to biodiversity intactness indicate what might happen to nature as culture. Modelling and mapping these indicators onto scenarios of China's future help us to understand how actions impact these different aspects of nature, and further work could explore the prioritization of these different indicators/synergies and trade-offs in specific pathways of development.

3.2 What do the results tell us about China today?

When looking across China in 2015, our results show that agriculture (grazing and cropland) occupies approximately 6 million km^2, compared with approximately 3 million km^2 composed of natural habitat (including land and water) (Table 9). In addition, there are approximately 153,000 km^2 of planted forest and 143,000 km^2 of settlements.

The largest biomes in China are montane grasslands and shrublands followed by temperate broadleaf and mixed forests (Figure 6). These biomes have very different land system compositions. The montane grassland and shrubland biome is composed of 28% natural grasslands, 14% grass-forest mix system and

12% low intensity grazing on non-degraded grasslands. The temperate broadleaf and mixed forest biome is made up of 21% low intensity agricultural systems, 20% high intensity agricultural systems and 18% agricultural villages and 15% medium intensity agricultural land systems.

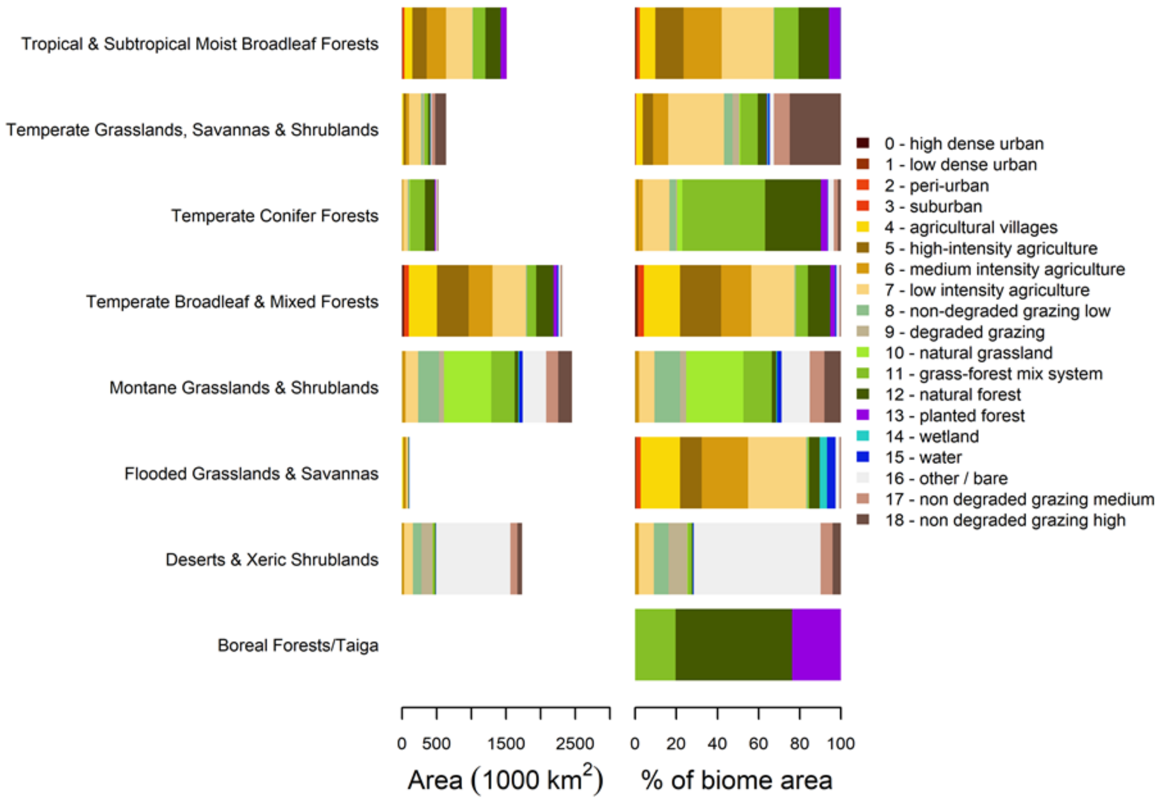


Figure 6. Absolute and relative area of each land system in the biomes of China in 2015.

Table 9. Summary table with area of each land systems within each broad system class, in different Biomes and in total for China. Areas are shown in 1,000 km^2. The ecoregion 'rock and ice' which covers 51,312 km^2 is excluded.

Description	Boreal Forests/ Taiga	Deserts, Xeric Shrublands	Flooded Grasslands, Savannas	Montane Grassland, Shrublands	Temperate Broadleaf, Mixed Forests	Temperate Conifer Forests	Temperate Grasslands, Savannas, Shrublands	Tropical, Subtropical Moist Broadleaf Forests	Total
Settlement systems									
High dense urban area	0.0	0.2	0.2	0.1	20.0	0.1	0.6	8.2	29.5
Low dense urban area	0.0	0.1	0.4	0.1	14.3	0.0	0.4	3.1	18.5
Peri-urban area	0.0	0.2	0.5	0.4	29.7	0.3	0.8	14.8	47.2
Sub-urban area	0.0	0.1	1.7	0.2	35.7	0.2	0.9	9.0	48.4
Cropland systems									
Agricultural villages	0.0	2.3	20.7	4.0	405.1	3.4	21.1	112.7	572.2
High intensity agriculture	0.0	4.8	11.4	9.8	460.0	3.4	32.0	208.1	729.6
Med-intensity agriculture	0.0	24.6	24.3	35.7	339.9	12.0	47.0	281.0	764.8
Low-intensity agriculture	0.0	126.6	30.5	181.8	482.4	67.3	172.8	382.0	1,444.0
Grazing systems									
Non-degraded grazing low	0.0	122.8	0.8	301.8	12.6	16.5	26.1	6.6	487.5

Non-degraded grazing medium	0.0	101.1	0.5	175.4	9.7	10.5	49.1	2.1	348.5
Non-degraded grazing high	0.0	70.0	0.3	197.1	8.6	7.6	158.9	1.2	443.8
Degraded grazing	0.0	158.7	0.0	73.0	4.4	3.5	21.2	0.4	261.4
Grass-forest mix system	0.1	32.1	0.6	340.5	132.9	209.6	54.0	177.6	949.5
Forest and natural systems									
Natural grassland	0.0	4.4	0.1	682.0	0.5	13.2	3.2	0.1	730.0
Natural forest	0.2	8.7	5.5	50.8	251.6	141.4	27.4	223.0	710.1
Planted forest	0.1	0.0	0.0	0.3	50.9	17.0	1.5	83.1	153.0
Other systems									
Wetland	0.0	1.4	3.9	12.3	4.0	0.4	3.5	0.0	25.6
Water	0.0	7.0	4.4	51.0	13.7	0.7	4.8	0.8	92.0
Other land	0.0	1,070.2	2.1	335.7	32.3	14.4	12.4	0.0	1,479.0

Across the scenarios we estimate a rise in the intensification of agriculture, with movement away from low intensity agriculture and low intensity grazing (Figure 7 and Figure 8B&C). As all scenarios include increased production to provide for an expanding population, the policy scenarios contain more pronounced intensification of agriculture to allow greater extent of restoration. The area of land under low-intensity agricultural systems is estimated to decrease by more than 1,300,000 km² by 2035 within the policy enacted scenarios of SSP1 and SSP2.

The extent of natural forests stays relatively constant in the baseline scenarios, but greatly expands in both policy enacted scenarios by 429,000 km² forecast for the policy enacted scenario of SSP1 and 483,000 km² forecast for the policy enacted scenario of SSP2 (Figure 7 and Figure 8D). The policy enacted scenario for SSP1 has the greatest restoration of non-forested areas of any scenario, and the policy enacted scenario for SSP2 has the greatest restoration of forested areas of any scenario (Figure 7 and Figure 8D). Planted forest increases in both baseline scenarios and decreases in both policy scenarios (Figure 7 and Figure 8D).

The scenarios show populations moving away from the most densely populated areas, with all scenarios projecting large increases in sub-urban areas (Figure 7 and Figure 8A).

When contrasting SSP1 with and without policy targets (Figure 7 I), the introduction of policy targets generates a larger change in area of all but two land systems: high-intensity agriculture (B.06) and non-degraded medium grazing (C.11). The overall pattern is similar when contrasting SSP2 with and without policy targets (Figure 7 II), despite the wider changes from the baseline. Only medium intensity agriculture (B.07) with no policy targets shows an opposite tendency with a reduction area rather than the residual increase expected for SSP1.

Analysing the inclusion of policy targets for both SSPs, similar patterns are found (Figure 7 III). The magnitude of change differs substantially for high- (B.06) and medium- intensity agriculture (B.07), as well as for non-degraded medium grazing (C.11); scenarios differ 2.5 to 5 times in these three instances.

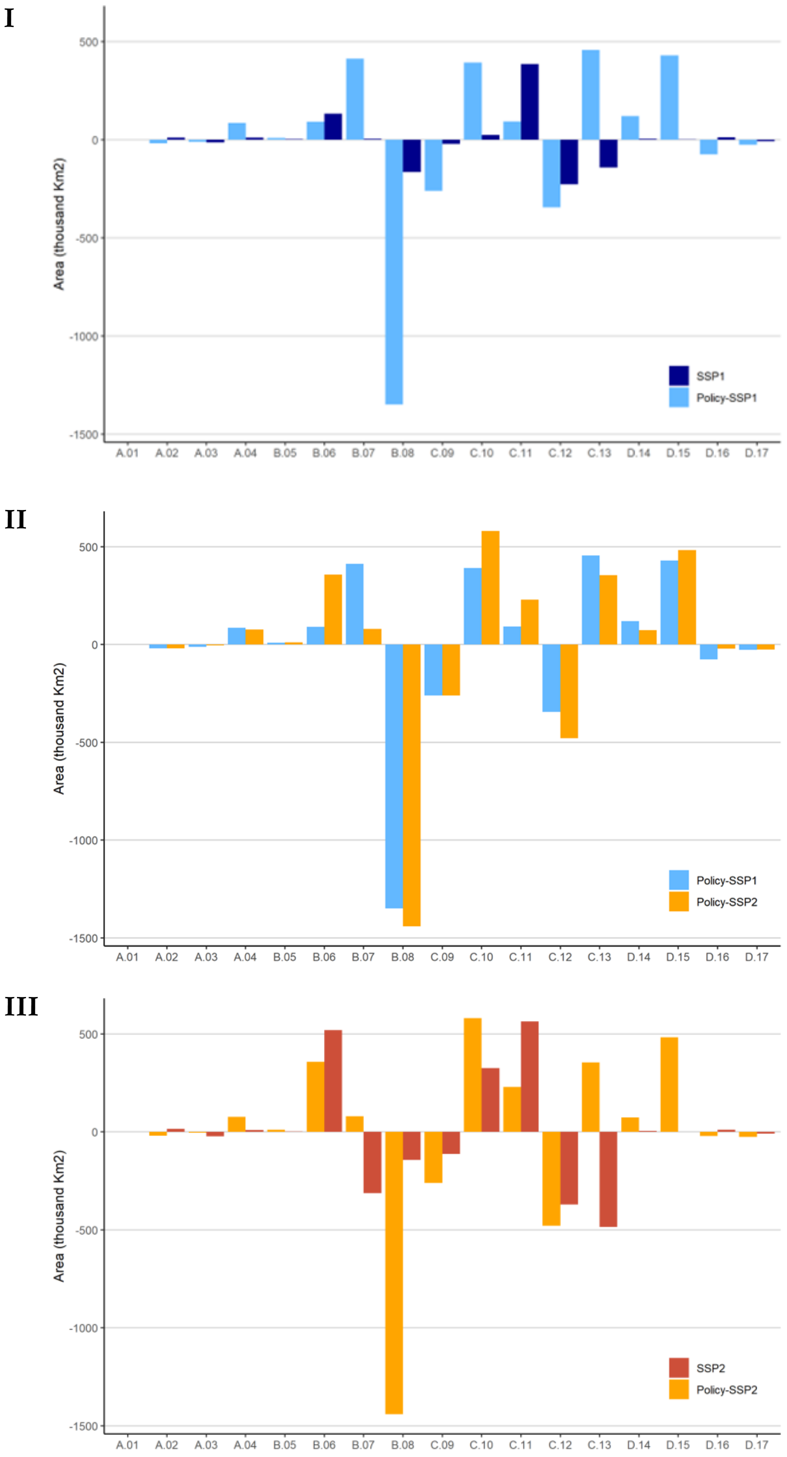


Figure 7. Changes in land systems (thousands of km^2) for the potential futures within broad classes as follows: settlement systems (A) with high dense urban (A.01), low dense urban (A.02), peri-urban (A.03), and suburban (A.04); cropland systems (B) with agricultural villages (B.05), high-intensity agriculture (B.06), medium intensity agriculture (B.07), and low-intensity agriculture (B.08); grazing systems (C) with degraded grazing (C.09), non-degraded grazing high (C.10), non-degraded grazing medium (C.11), non-degraded grazing low (C.12), and grass-forest mix system (C.13); and forest and natural systems (D) with natural grassland (D.14), natural forest (D.15), planted forest (D.16), and other natural areas (D.17). Changes smaller than 1,000 km2 may not be visible. I) compares SSP1 with SSP1 policy, II) compares SSP2 with SSP2 policy, and III) compares SSP1 policy and SSP2 policy.

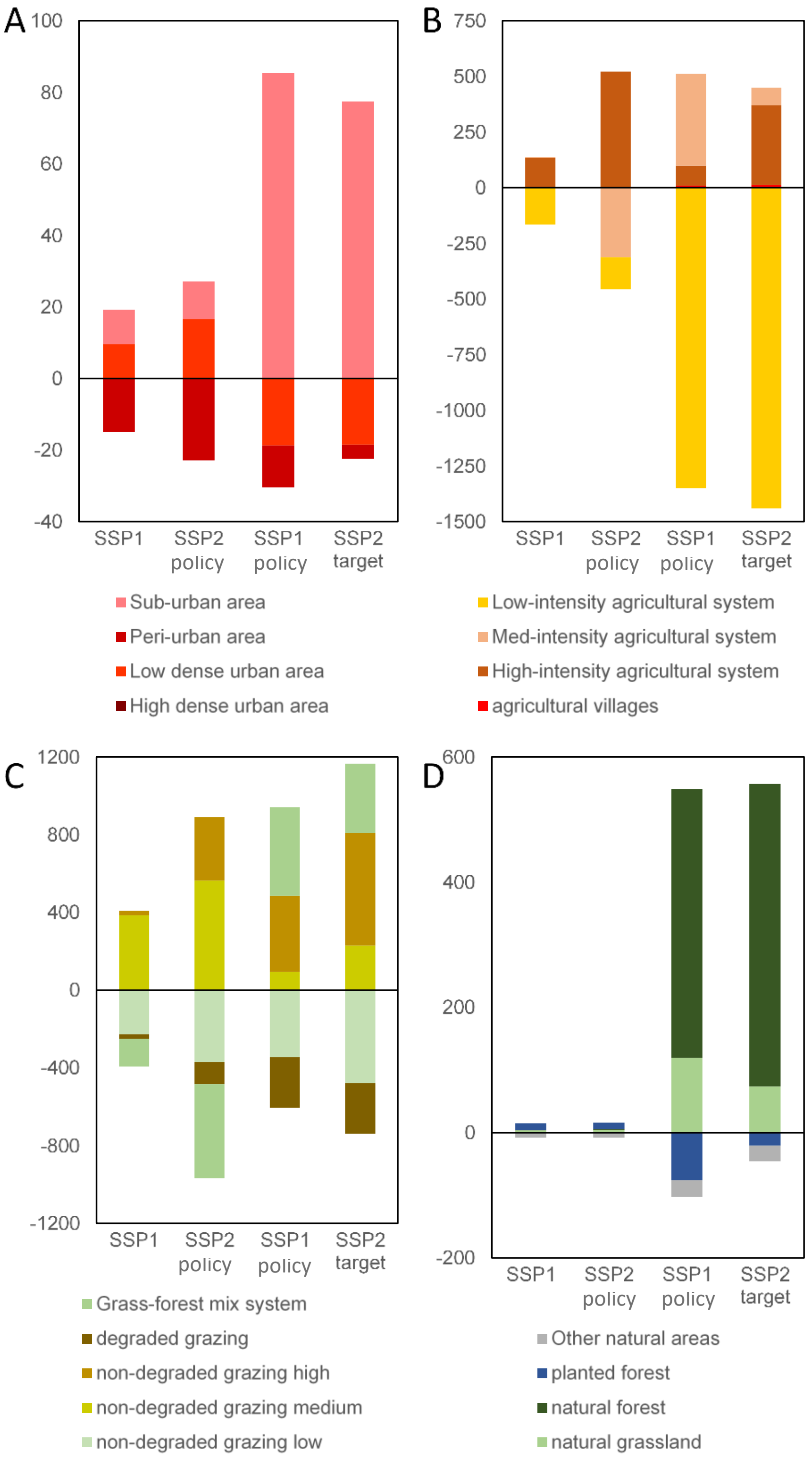


Figure 8. Changes in land systems (thousands of km2) for the potential futures within broad classes settlement systems (A), cropland systems (B), grazing systems (C) and forest and natural systems (D). Note the bars show cumulative contributions from each land system.

The above plots show the absolute change in land systems categories but do not show the transitions from one land system type to another. Figure 9 shows that, for the baseline SSPs, the majority of change occurs between cropland and grazing systems (Figure 9, left hand side panels) resulting in approximately equivalent proportions. When policy targets are considered, greater loss of cropland extent is required to allow the growth of forest area and the renovation of grazing systems and natural grasslands (Figure 9, right hand side panels). It is noticeable that in all scenarios cropland is lost to provide urban areas for the growing population; however, as described previously and seen in Figure 8, these new urban areas are likely to be low-density suburban areas.

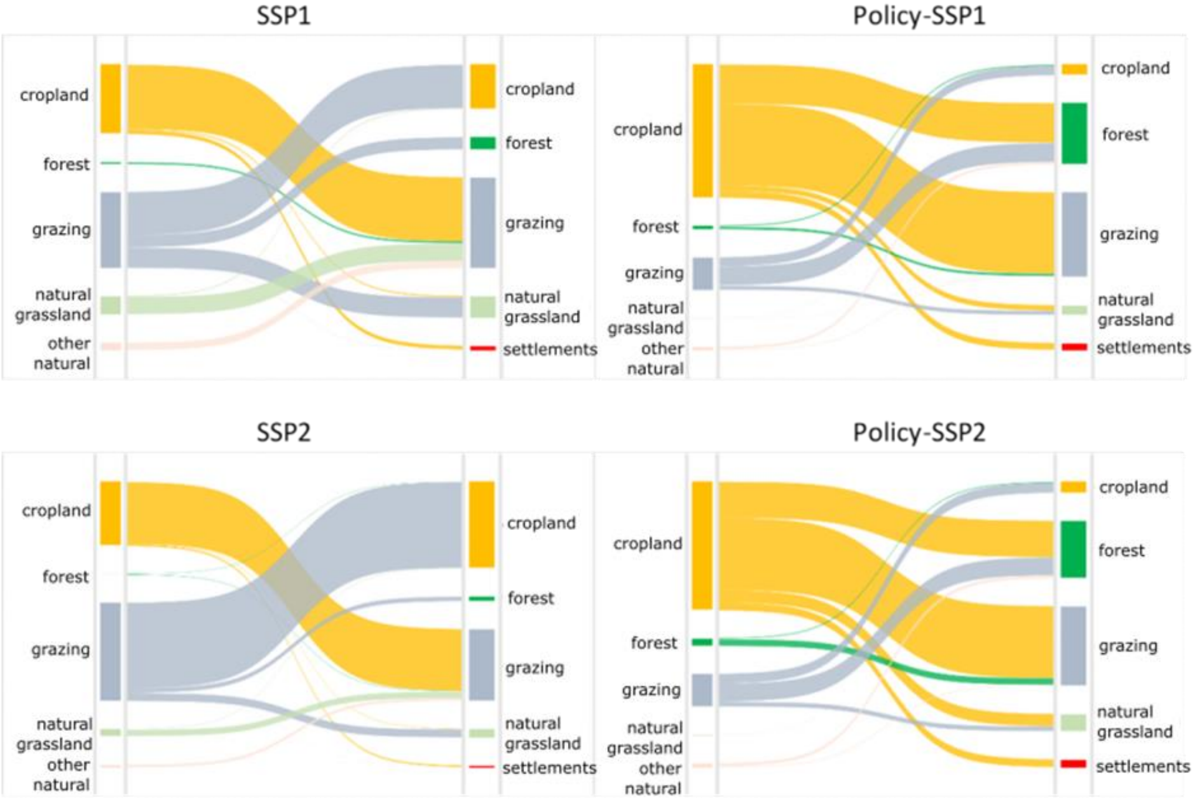


Figure 9. Transitions in land systems for the potential futures within broad classes settlement systems (red), cropland systems (yellow), grazing systems (grey) and forest and natural systems (natural grassland in light green, forest in dark green, other natural areas in pink). The width of land systems representation and transition bands are illustrative of the area that undergoes change; those areas that stay the same are not represented.

Above we describe broad patterns that have occurred across China, but there are regional differences in scenario outcomes. To highlight how different areas are likely to respond to future changes, we have selected four distinct regions with differing natural habitats, levels of urbanisation and production requirements that have undergone sometimes contrasting changes. These regions are:

Region A: a forested region encircled by densely populated and productive areas in the north and northeast of China that includes land from Beijing, Tianjin and the provinces of Heilongjiang, Jilin, Liaoning, Inner Mongolia, and Hebei;

Region B: an arid region in the northwest of China where desert and scrub give way to natural grasslands that includes land from the Xinjiang Uygur Autonomous Region;

Region C: a natural grassland region in the south of China that has been converted to extensive grazing and agriculture including land from the province of Yunnan; and

Region D: an agricultural region in the centre of China that includes land from the province of Shaanxi and Shanxi.

We describe these areas in more detail below as to the changes in land systems that are projected for each area, and we will refer to these areas throughout the document to highlight biodiversity responses within different circumstances.

The region illustrated in Figure 10 (Region A) presents noticeable areas of natural forest encircling vast areas of agricultural production. This area is predicted to undergo intensification of agricultural production under all potential futures. Particularly in the policy scenarios, the agricultural intensification allows extensive restoration of forested habitat. This is noticeable in areas in the far north and in eastern Lianoning and Jilin. Large areas of planted forest visible in 2015 and in the baseline scenarios are restored within the policy scenarios. This region is also characterised by settlement systems, particularly around Beijing and Tianjin. The policy scenarios project great changes to these areas, with a move towards less densely populated suburban areas surrounded by areas of restored grasslands.

An arid region in the north-west of China is illustrated in Figure 11 (Region B). This region is dominated by a large area of desert and scrub that gradually gives way to grasslands. This area sees noticeable shifts in the grazing systems with significant increases of non-degraded medium- and high- grazing, accompanied by reduction of the areas with degraded grazing and non-degraded low grazing.

Changes projected for the potential futures within a grassland system in the south of China are presented in Figure 12 (Region C). This region presents an evident area of increase of grassland and forest, expanding throughout the western and southern sections. Areas of planted forest are visible on the baseline scenario and are kept mostly stable.

Changes in land systems projected for the potential futures within the predominantly agricultural region in the centre of China are presented in Figure 13 (Region D). This region is characterised by settlement systems with notable changes in its surrounding areas. There is an increase in grass-forest mix systems and natural grassland, and a clear increase in agricultural systems of medium- and high- intensity, particularly in the scenarios that incorporate policy targets.

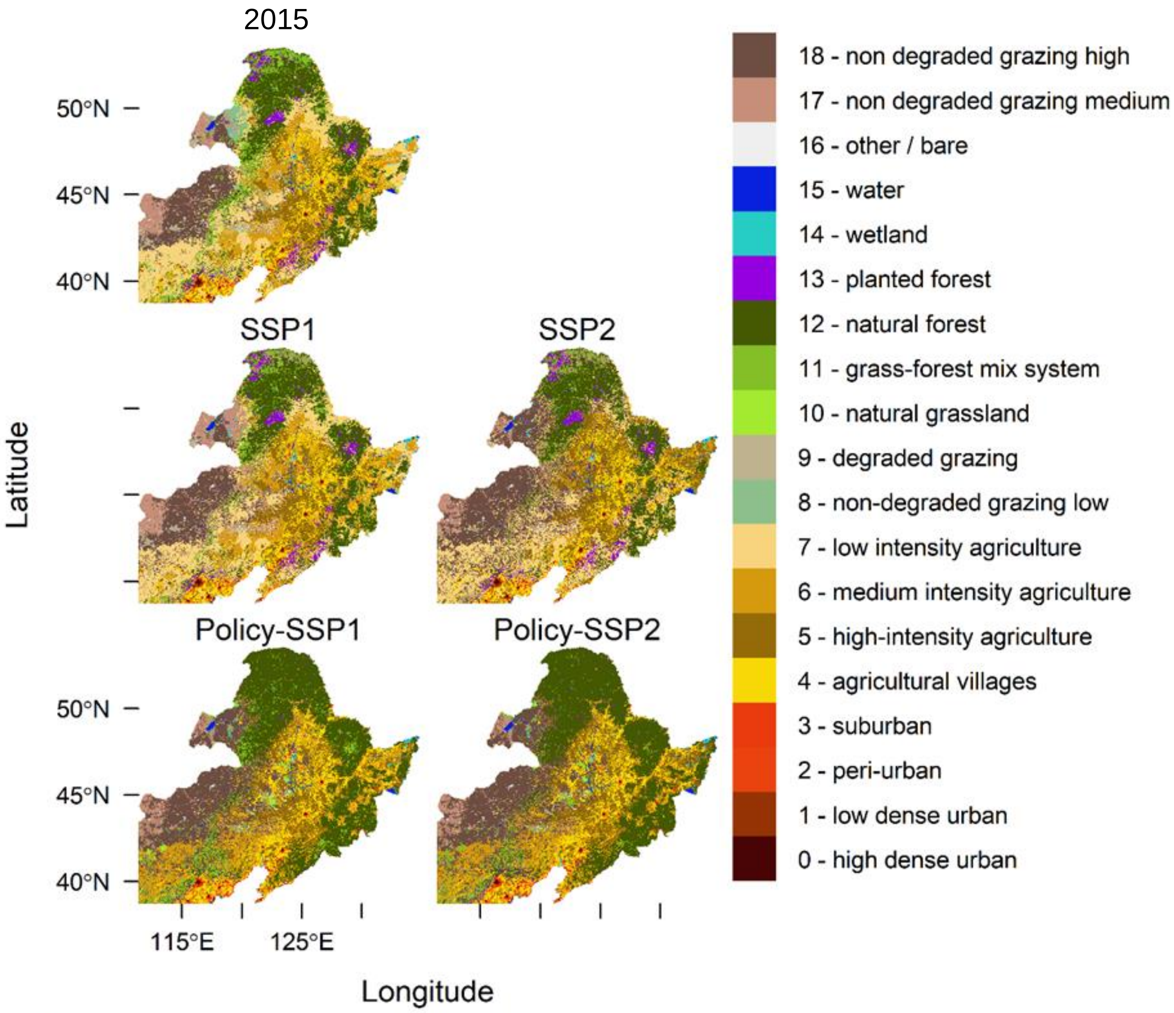


Figure 10. Land use patterns within a forested region in the north and northeast of China (Region A) predicted by four scenarios between 2015 and 2035.

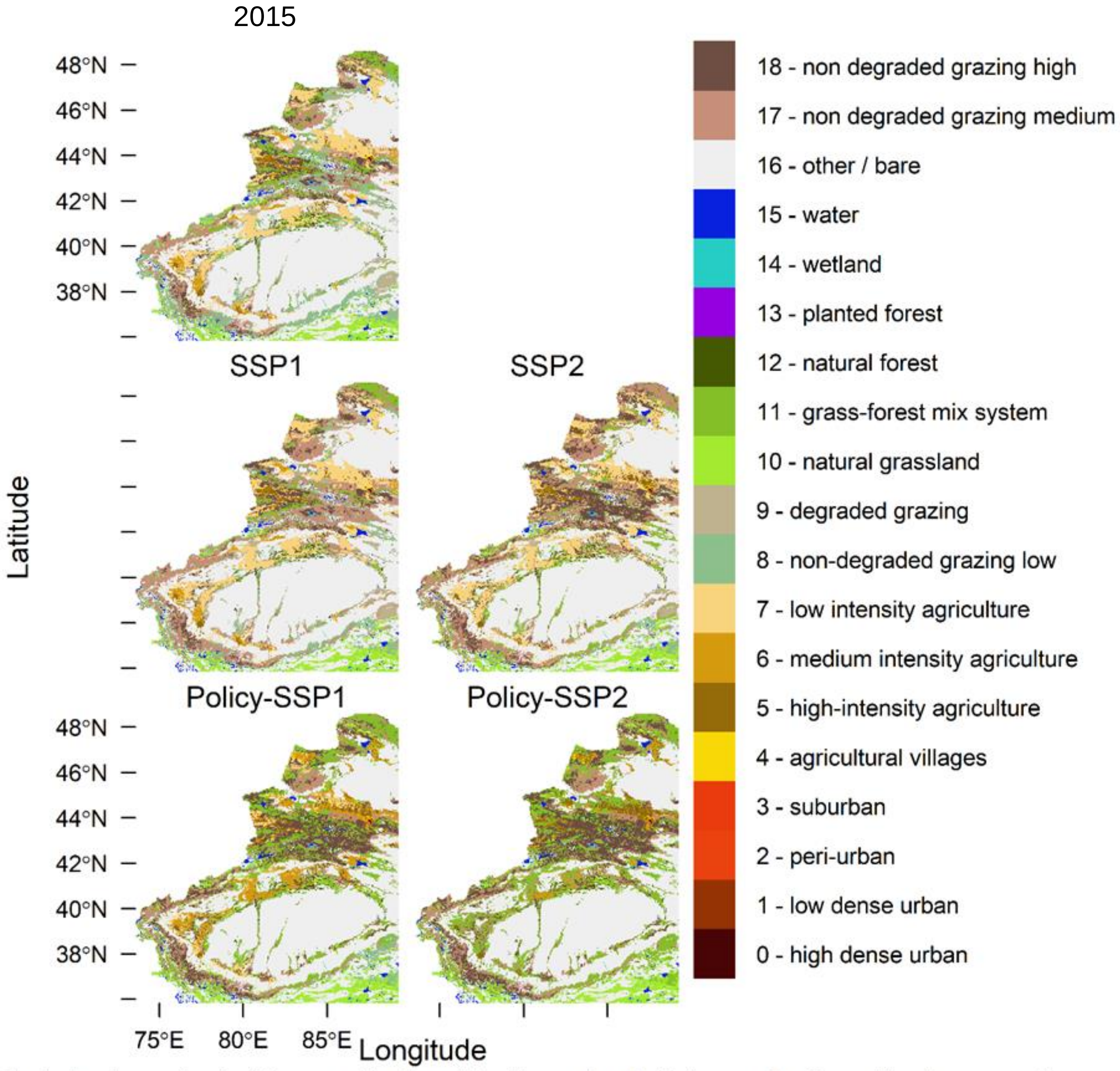


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Figure 11. Land use patterns within an arid region in the north west of China (Region B) predicted by four scenarios between 2015 and 2035.

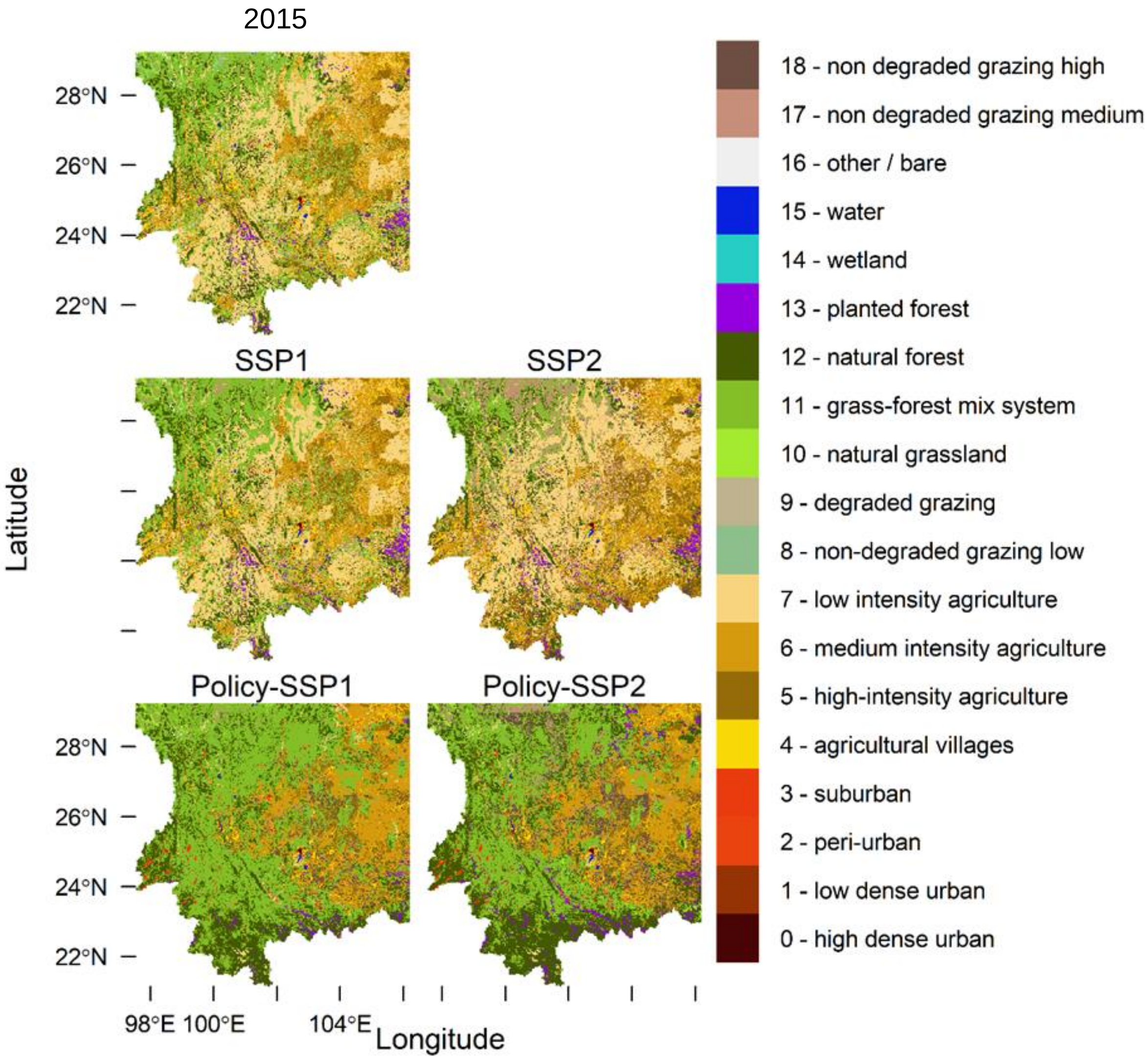
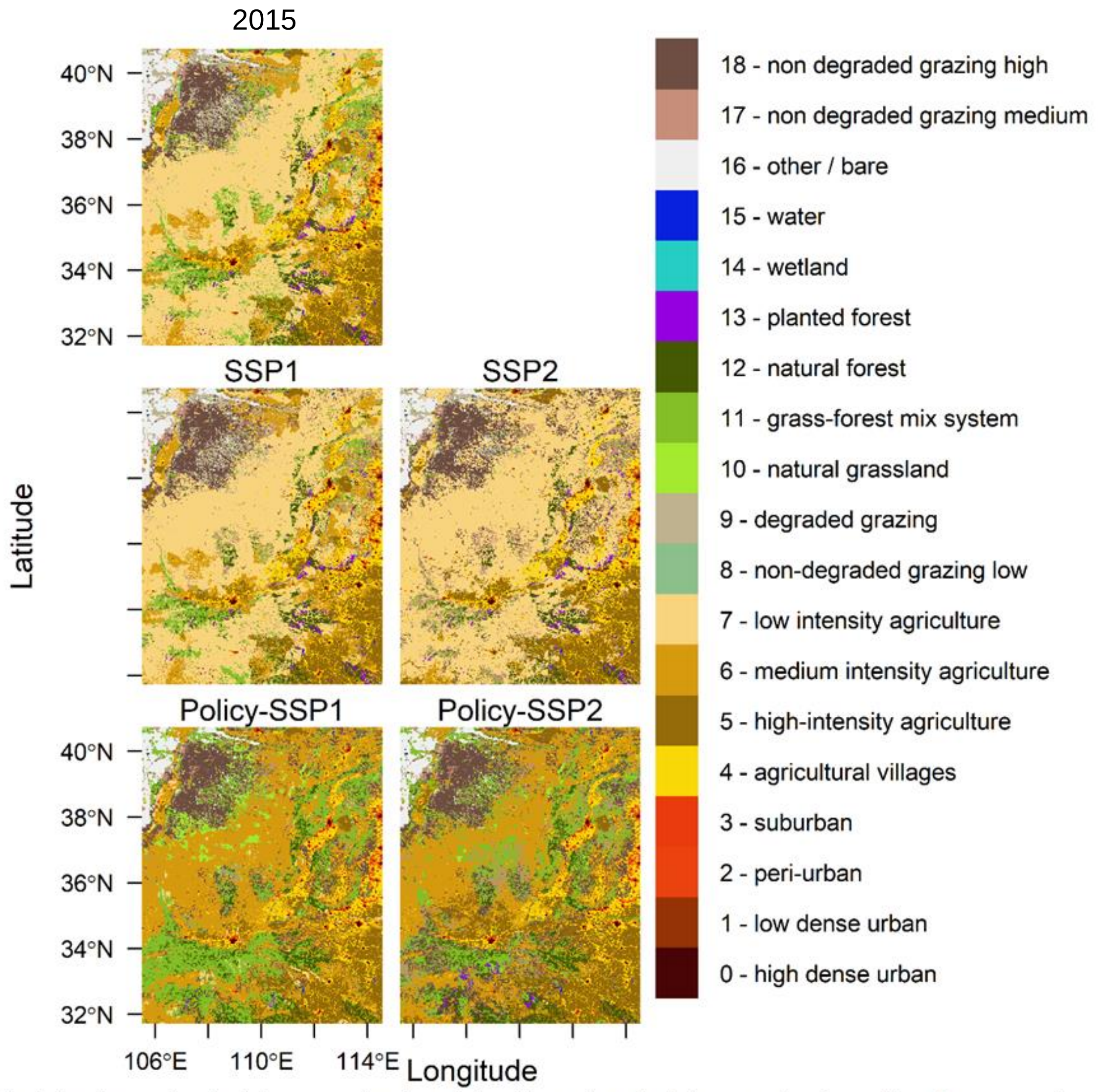


Figure 12. Land use patterns within a grassland region in the south of China (Region C) predicted by four scenarios between 2015 and 2035.



2015

SSP1

SSP2

Policy-SSP1

Policy-SSP2

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Figure 13. Land use patterns within an agricultural region in the centre of China (Region D) predicted by four scenarios between 2015 and 2035.

3.3 Habitat change

Focusing now on the natural habitat (i.e., natural grassland, natural forest and grass-forest mix system), overall, both the policy enacted scenarios for SSP1 and SSP2 estimated a net increase in area from 2015, with estimated increases of 42.04% and 38.18% respectively. However, the baseline scenarios for SSP1 and SSP2 both forecast decreases in natural habitat area between 2015 and 2035 (by 5.92% and 20.01% respectively).

Overall, no areas of current natural forests were estimated to be lost in any future scenarios. New areas of natural forest were predicted in all future scenarios (Table 10). Large areas of grass-forest mix systems were predicted to be lost in all future scenarios, however, at the same time the policy enacted scenarios were predicted to have large areas of new grass-forest mix systems. Therefore, leading to a net gain of grass-forest mix systems in the policy scenarios (Table 10). In the policy enacted scenarios, small areas of natural grassland were estimated to be lost, and at the same time, large areas of new natural grasslands were predicted. Therefore, leading to a net gain in the area of natural grasslands in these scenarios (Table 10).

Looking at the habitat types in more detail, we can see biomes may present varying changes resulting from each alternate scenario. For example, the baseline scenarios for SSP1 and SSP2 forecast losses in the grassland-forest mix system with 143,016km^2 and 476,776 km^2 respectively, whereas the natural forest and natural grassland types are predicted to have an overall increase in all the future scenarios. This is due to an increase in levels of intensification of agriculture in the policy scenarios which would consequently make way for more restoration of natural forests and grasslands. The policy enacted SSP1 scenario forecasts a greater overall increase in habitat of natural grassland (117,396 km^2) and grass-forest system (457,464 km^2) compared to the policy enacted SSP2 scenario (71,876 km^2 and 359,796 km^2 for natural grassland and grass-forest system respectively). Whereas the policy enacted SSP2 scenario forecasts a greater overall increase in the habitat of natural forests (469,104 km^2) as compared to the policy enacted SSP1 scenario (417,028 km^2) (Table 11). The changes among each individual habitat type which show higher values for policy enacted SSP2 are nonetheless balanced by the forecast of a greater change in the overall natural habitat for the policy enacted scenario for SSP1.

Natural forests, broken per biome, are all estimated to increase under all future scenarios. Biomes holding natural grasslands are estimated to increase under the policy enacted SSP1 and SSP2 scenarios except for Boreal Forests/Taiga. All biomes except Deserts & Xeric Shrublands and Temperate Conifer Forests are predicted to undergo an overall decrease in area of natural habitat in both SSP1 and SSP2 whereas there was an overall increase in area of natural habitat under SSP1 policy and SSP2 policy scenarios for these biomes.

Table 10. Habitat change from 2015 in different future scenarios s in km².

Change	SSP1 (change from 2015 in km²)			Policy-SSP1 (change from 2015 in km²)			SSP2 (change from 2015 in km²)			Policy-SSP2 (change from 2015 in km²)		
	natural grassland	grass-forest mix system	natural forest	natural grassland	grass-forest mix system	natural forest	natural grassland	grass-forest mix system	natural forest	natural grassland	grass-forest mix system	natural forest
loss	19,736	203,716	0	1,312	316,656	0	19,736	680,216	0	2,004	557,340	0
unchanged	729,888	765,040	754,488	748,312	652,100	754,488	729,888	288,540	754,488	747,620	411,416	754,488
gain	23,260	60,592	656	120,404	772,908	429,552	24,344	196,144	848	75,604	912,688	483,216

Table 11. Habitat change from 2015 in different future scenarios for each biome. Ecoregion 'rock and ice' which covers 51,312 km^2 is excluded.

Biome	SSP1 (change from 2015 in km^2)			Policy-SSP1 (change from 2015 in km^2)			SSP2 (change from 2015 in km^2)			Policy-SSP2 (change from 2015 in km^2)		
	natural grassland	grass-forest mix system	natural forest	natural grassland	grass-forest mix system	natural forest	natural grassland	grass-forest mix system	natural forest	natural grassland	grass-forest mix system	natural forest
Deserts & Xeric Shrublands	-936	-13,716	0	29,412	161,612	480	-776	59,216	4	6,196	284,840	1,380
Montane Grasslands & Shrublands	7,500	-41,340	108	58,004	161,952	18,476	8,440	-152,628	208	37,064	126,992	19,496
Temperate Conifer Forests	-840	5,156	104	1,492	33,004	57,028	-764	-93,712	116	2,324	-38,040	64,832
Temperate Grasslands, Savannas & Shrublands	-2,332	-29,904	136	14,936	-8,104	11,324	-2,332	-39,688	136	3,200	28	14,560
Flooded Grasslands & Savannas	-120	-220	8	3,524	440	14,876	-120	-508	12	3,996	2,192	14,964
Temperate Broadleaf & Mixed Forests	-456	-37,564	64	8,576	70,848	133,492	-456	-96,828	64	7,620	25,740	155,368
Boreal Forests/Taiga	0	-12	0	0	-52	124	0	-16	0	0	-60	132
Tropical & Subtropical Moist Broadleaf Forests	-80	-25,416	96	1,452	37,764	181,228	-80	-152,612	100	11,476	-41,896	198,372
Total	**2,736**	**-143,016**	**516**	**117,396**	**457,464**	**417,028**	**3,912**	**-476,776**	**640**	**71,876**	**359,796**	**469,104**

3.4 Impacts on biodiversity significance

From a total of 614 threatened or near threatened species whose ranges overlapped the national scenario outputs, 604 species have habitat in their range in 2015 and were used in the analysis. Nearly a quarter of these species were mammals (n=141), and the rest split between amphibians (n=236) and birds (n=227). In terms of their conservation status, a third of amphibians and mammals were in the two highest IUCN threat categories, compared to only a fifth of birds. A large proportion of birds (~40%) were also in the lowest threat category considered (Near Threatened, NT).

In terms of species level change, the SSP1 baseline scenario forecasts that over one in twenty species lose moderate to high proportions (>5%) of habitat and roughly the same number of species gain an equivalent amount of habitat (Figure 14). However, the SSP1 scenario with policy enacted estimates that by 2035 over half the species will increase their area of habitat by more than 5%, with one in ten species showing even higher gains (>30%) (Figure 14). By contrast only 2% of species are forecast to lose >5% of their habitat (Figure 14).

When examining the future forecast by the baseline SSP2 scenario, nearly half the study species lose more than a moderate amount (>5%) of their habitat, with one in ten showing large declines (>30%) (Figure 14). However, less than one in twenty species gain more than 5% of their habitat. The pattern observed in the future quantified in the SSP2 scenario with policy enacted, is nearly identical to that in the SSP1 policy enacted scenario with over half the species analysed estimated to increase their habitat by moderate to high proportions, and very few (one in fifty) losing equivalent proportions.

When considering biome level change, the SSP1 scenario forecasts that there will be small biodiversity significance gains on average by 2035 in the Temperate Conifer Forests biome, but little to no overall change in any other biomes (Figure 15). The SSP1 policy enacted scenario forecasts no losses of biodiversity significance, on average, in any biome. The most notable increases in biodiversity significance occur in forest biomes and, in particular the Tropical and Subtropical Broadleaf Forest, followed by the Temperate Conifer Forests. Boreal forests and Taiga biomes showed almost no change in biodiversity significance (Figure 15). Grassland biomes are forecast to have much smaller increases in biodiversity significance than forested biomes in this scenario. The SSP2 scenario is characterised by loss of biodiversity significance in the forest biomes, with estimates showing that both Tropical and Subtropical Broadleaf Forest and Temperate Conifer Forests may experience similar declines. The scenario forecasts that all other biomes will undergo small losses or gains in biodiversity significance. In terms of average change in biodiversity significance per biome, none of the biomes are forecast to undergo overall loss (Figure 15). The estimates show that similar patterns to the SSP1 policy enacted scenario are likely with the SSP2 policy enacted scenario, with land use changes likely to cause the most positive changes in the forest Tropical and Subtropical Broadleaf Forest and Temperate Conifer Forests. The grassland biomes are estimated to undergo much smaller increases in biodiversity significance than forested biomes with the only relevant gains in biodiversity significance estimated to occur in the Flooded Grasslands and Savannas biome (Figure 15).

Overall, biodiversity significance is estimated to be most heavily impacted in the SSP2 baseline scenario, followed by the SSP1 baseline scenario. In this scenario some of the losses in biodiversity significance are masked by gains (at least at the biome level). Both scenarios with policy enacted (SSP1Policy and SSP2 Policy), forecast impressive increases in biodiversity significance, especially in forested biomes (notably Tropical and Subtropical Broadleaf Forest). Patterns of change, unsurprisingly, estimate that the highest losses and gains will be in areas that are already of high significance in 2015. In these areas the significance typically arises from the presence of multiple species with small ranges, and so any changes in habitat within their ranges can have large impacts. As these areas of high change typically have values orders of magnitude higher than those surrounding them, this can drive much of the overall impacts seen at the biome level (Figure 15**Fehler! Verweisquelle konnte nicht gefunden werden.**).

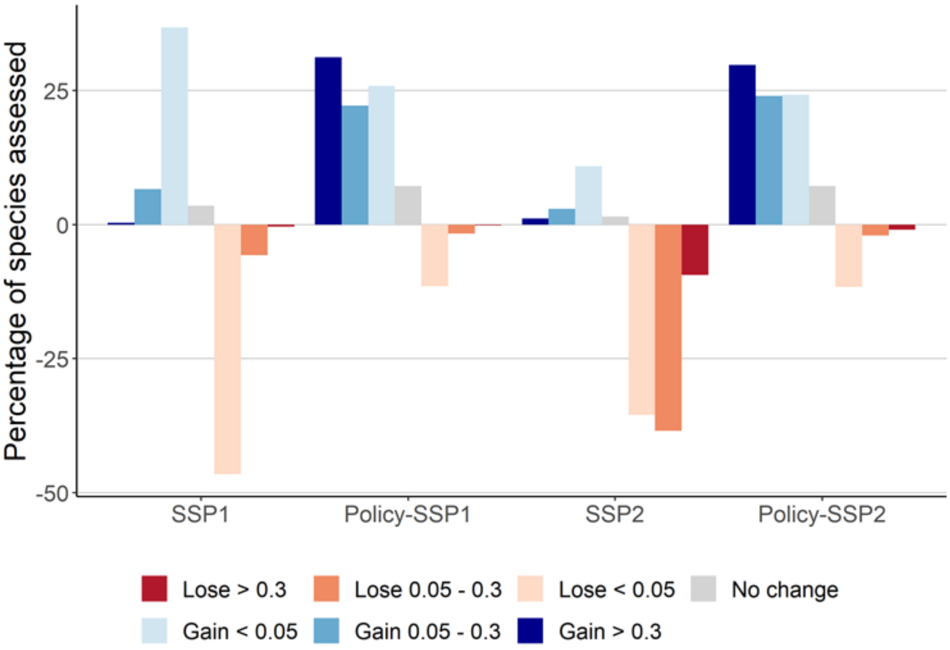

Figure 14. Percentage of study species gaining and losing habitat predicted by four scenarios, split into classes to show different proportions of habitat loss (shades of red) and gain (shades of blue).

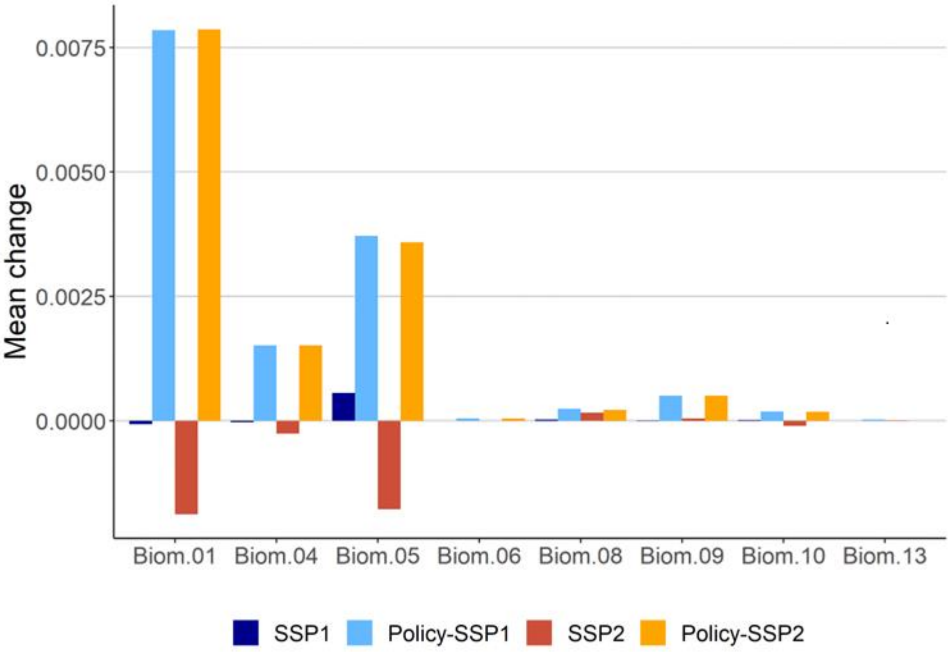

Figure 15. Comparison of changes per biome and scenario for the biodiversity significance metric, predicted by four scenarios. Biom 01 – Tropical & Subtropical Moist Broadleaf Forests; Biom 04 – Temperate Broadleaf & Mixed Forests; Biom 05 – Temperate Conifer Forests; Biom 08 – Temperate Grasslands, Savannas & Shrublands; Biom 09 – Flooded Grasslands & Savannas; Biom 10 – Montane Grasslands & Shrublands; Biom 13 – Deserts & Xeric Shrublands.

In all scenarios the amphibians are forecast to typically undergo the largest changes (loss and gains) in habitat and birds the least. The main reason for this is due to this group having typically smaller range sizes, thus small changes in absolute area of habitat, can translate into large proportional changes. Conversely, as birds have larger ranges, on average, than mammals or amphibians this explains the smaller projected impacts in the different scenarios. The prevalence of habitat generalists, vs specialists are also a consideration when understanding the differences between these taxonomic groups, although this is not explored further in this analysis.

We discuss results for two types of change to biodiversity significance in this analysis, species-level and biome-level. As the biome level is an average score across the biome, this may hide that some species are forecast to lose large proportions of their habitat and other species gaining similarly large proportions of habitat. In such cases, other threats may be at play beyond habitat loss, such as hunting etc., (as discussed in Chapter 2). Thus, a simple "accounting" approach should not be the only consideration when interpreting these results.

When considering the prevention of global extinction, with the exception of the baseline SSP1 scenario, all other scenarios projected that a species of horned toad, *Megophrys liboensis*, will lose all its habitat by 2035. This species has a small range and was only recently described (hence a Data Deficient (DD) threat status (according to the IUCN Red List[13]). This highlights that, in addition to the conservation-focused policies shown here, additional measures may be needed. One example is creating a conservation 'safety-net', typically through habitat protection and management. This is a key factor in limiting this kind of irreversible loss, with methods such as systematic conservation planning (Margules & Pressey, 2000) being well suited to ensuring species representation when identifying such areas.

When examining results at a regional level, we clearly see the impact of China's environmental policies on biodiversity significance – within all regions examined, biodiversity significance is increased where forest or grassland restoration occurs (Figures 16-20). Of note, are the results for Region C, a grassland region in the south of China (Figure 18). The results for this region show a stark contrast, with little change to biodiversity significance predicted by SSP1, widespread losses of biodiversity significance predicted by SSP2, and widespread gains in biodiversity significance predicted by both policy enacted scenarios. These results reinforce the conclusion that the conservation policies encoded in the policy enacted scenarios (including forest and grassland restoration) have a positive effect on biodiversity when they are implemented.

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[13] IUCN Red List of Threatened Species - https://www.iucnredlist.org/

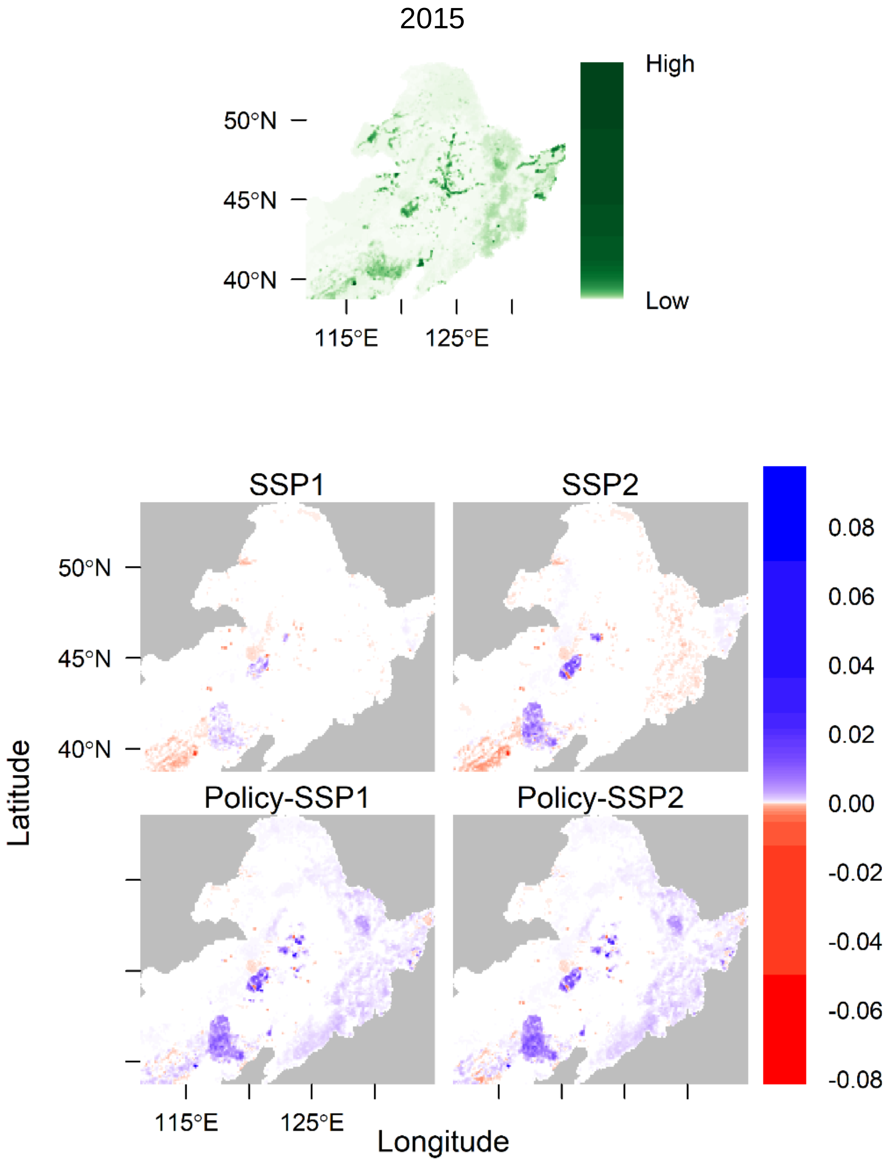

Figure 16. Biodiversity significance in 2015 (top panel) and changes to biodiversity significance predicted by four scenarios between 2015 and 2035 within a forested region in the north and northeast of China (Region A).

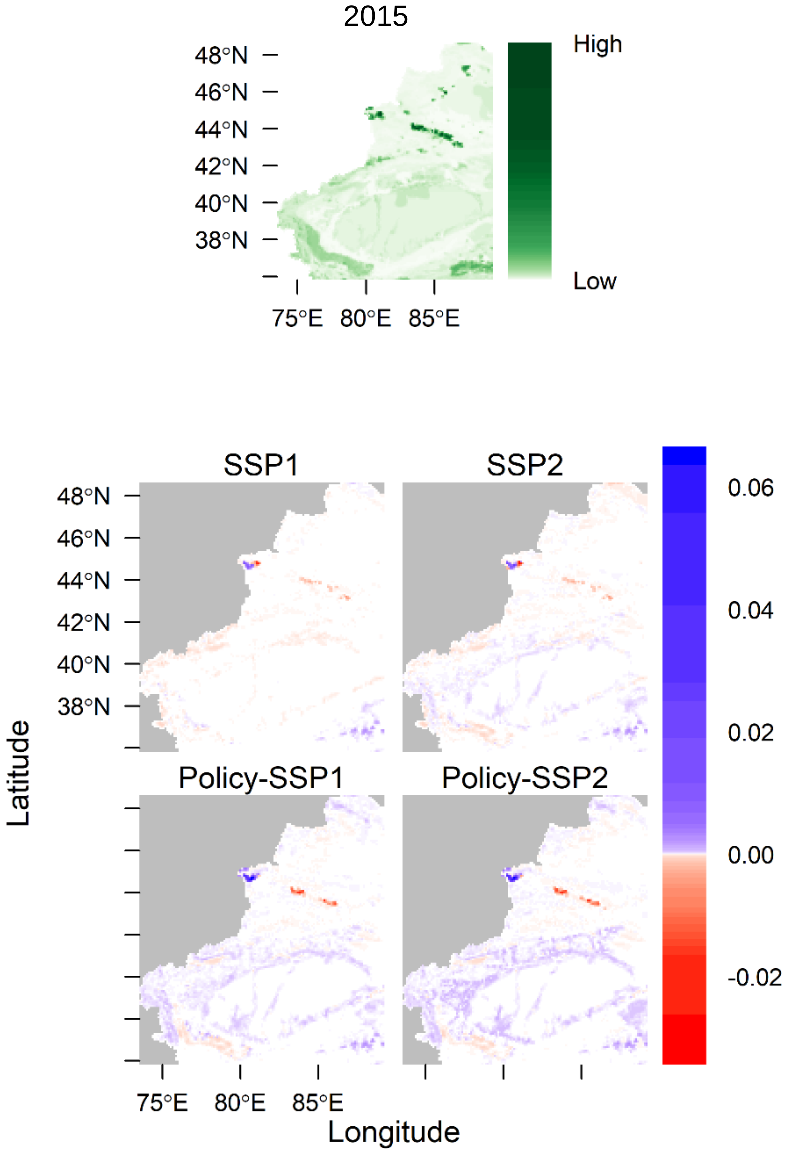

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Figure 17. Biodiversity significance in 2015 (top panel) and changes to biodiversity significance predicted by four scenarios between 2015 and 2035 within an arid region in the north-west of China (Region B).

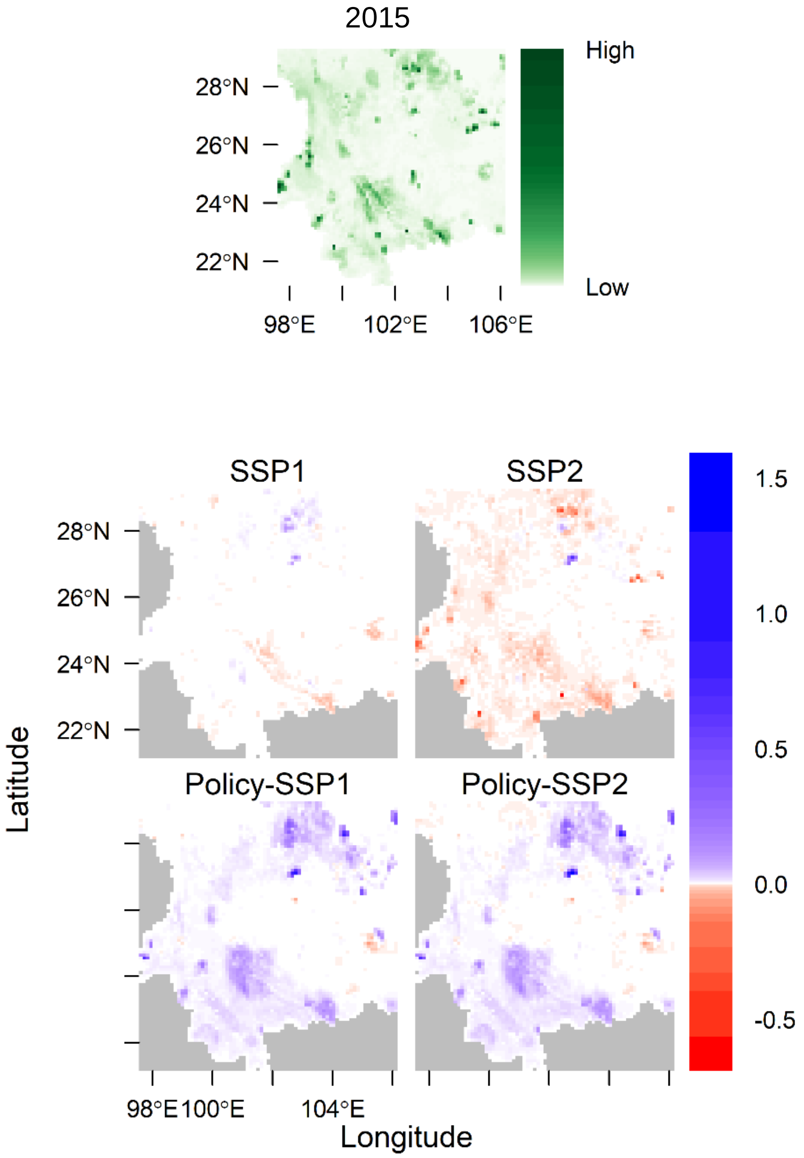

Figure 18. Biodiversity significance in 2015 (top panel) and changes to biodiversity significance predicted by four scenarios between 2015 and 2035 within a grassland region in the south of China (Region C).

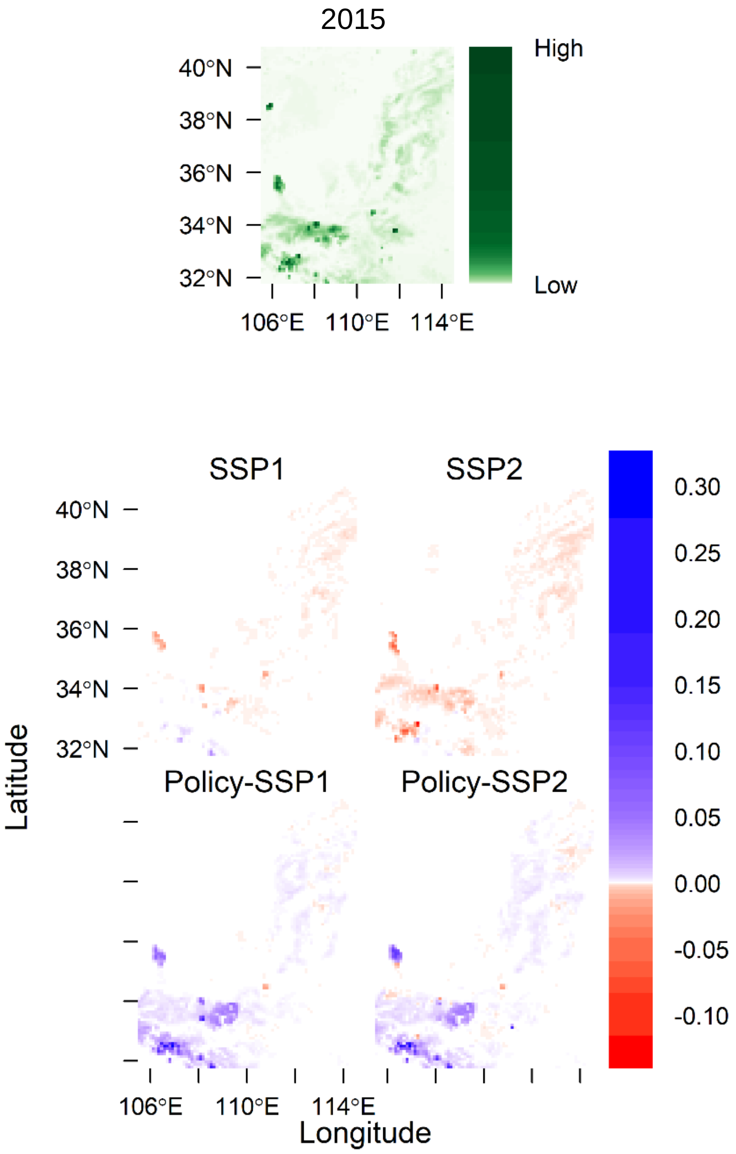

Figure 19. Biodiversity significance in 2015 (top panel) and changes to biodiversity significance predicted by four scenarios between 2015 and 2035 within an agricultural region in the centre of China (Region D).

3.5 Impacts on biodiversity intactness

On average, terrestrial biodiversity intactness within China was estimated to decrease by 2035 in all scenarios assessed (Table 12). This is not surprising given that all scenarios included an increase at the national level in crop and livestock production through to 2035. However, the future quantified in the SSP1 scenario is estimated to have the lowest fall in biodiversity intactness with approximately 1% loss in mean biodiversity intactness forecast by 2035 (Table 12). In contrast, the SSP2 baseline scenario forecasts an average drop of nearly 5% in biodiversity intactness (Table 12). The policy enacted and baseline scenarios for SSP2 forecast approximately similar results; however, the policy enacted version of SSP1 estimates a larger average drop in biodiversity intactness than the baseline scenario (Table 12).

It may at first seem surprising that the policy enacted scenario for SSP1 predicts a greater loss of biodiversity than the baseline scenario given that the policies have been selected to enhance nature. However, the policy enacted scenarios rely upon an increase in the intensity of agricultural production to enable large areas to be set aside for restoration. It can take many years for biodiversity to re-establish in areas of restoration, and by 2035 (the endpoint of our scenarios) the areas of restoration are not sufficiently mature to counter the degradation of biodiversity in areas where production has intensified. To examine this in greater depth, we produced a further set of scenario projections where it was assumed that all areas that were marked for restoration had reached their full biodiversity potential (as might occur if these areas were left untouched for several decades) (Table 12). In all scenarios, the maturation of restored areas led to a recovery of biodiversity when compared to the projected state of biodiversity in 2035, but the change was particularly pronounced when considering SSP2. This scenario quantified a 'business as usual' future where future trends in development are based upon historic trends. Socioeconomic situations do improve in this scenario, but at a gradual pace. The SSP2 scenario with policy targets enabled shows a marked improvement in biodiversity intactness compared to the baseline scenario.

Table 12. Changes in BII forecast in scenarios with results provided for likely outcome in 2035 as well as what would happen in the future if restored areas were left untouched.

Scenario	Mean BII Change by 2035	Mean BII Change with Maturity Assumption
SSP1	-1.31	-1.24
SSP2	-4.70	-4.49
Policy-SSP1	-3.08	-1.80
Policy-SSP2	-4.61	-3.20

We can see some of these trends in greater detail when examining regional development. Within a forested region in the northeast of China we see the balance between the degradation of biodiversity found in the intensification of agriculture with the improvement of biodiversity estimated in areas of restoration (Region A; Figure 20). The SSP1 scenario shows the least change of all scenarios in this region, with minimal areas of restoration and therefore minimal areas of intensification. SSP1 focusses on sustainable solutions including decrease of waste, therefore allowing for increases in living standards without large increases in production.

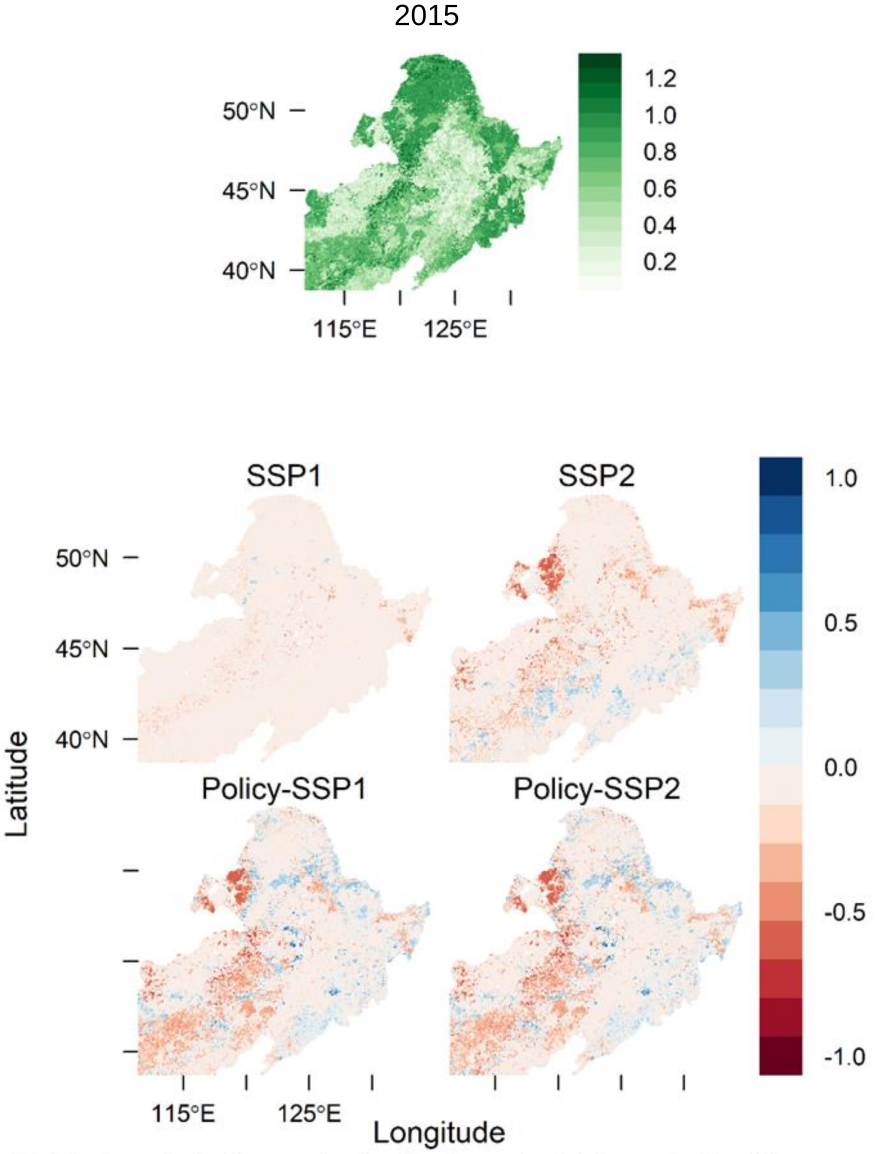

Figure 20. Biodiversity intactness in 2015 (top panel) and changes to biodiversity intactness predicted by four scenarios within a forested region in the north-east of China (Region A).

The policy enacted scenarios, in contrast, show large areas of forest restoration along the eastern and southern perimeter with grassland and grass-forest mixed habitat restoration in the southwest. These areas of restoration are enabled through an increase in agricultural intensity in central areas.

Within the northwest of China, the scenarios predict large changes in the valleys surrounding the arid centre of Xinjiang (Region B; Figure 21). The policy enacted scenarios forecast the restoration of large areas of grassland across these mountainous habitats, but this is paired with expansion and establishment of high intensity agriculture, especially in the productive zone between Urumqi and Ili Kazak Autonomous Prefecture. Where grassland restoration occurs, biodiversity intactness is estimated to increase by up to 100%; however, biodiversity intactness also declines by up to 100% in areas of high intensity agriculture.

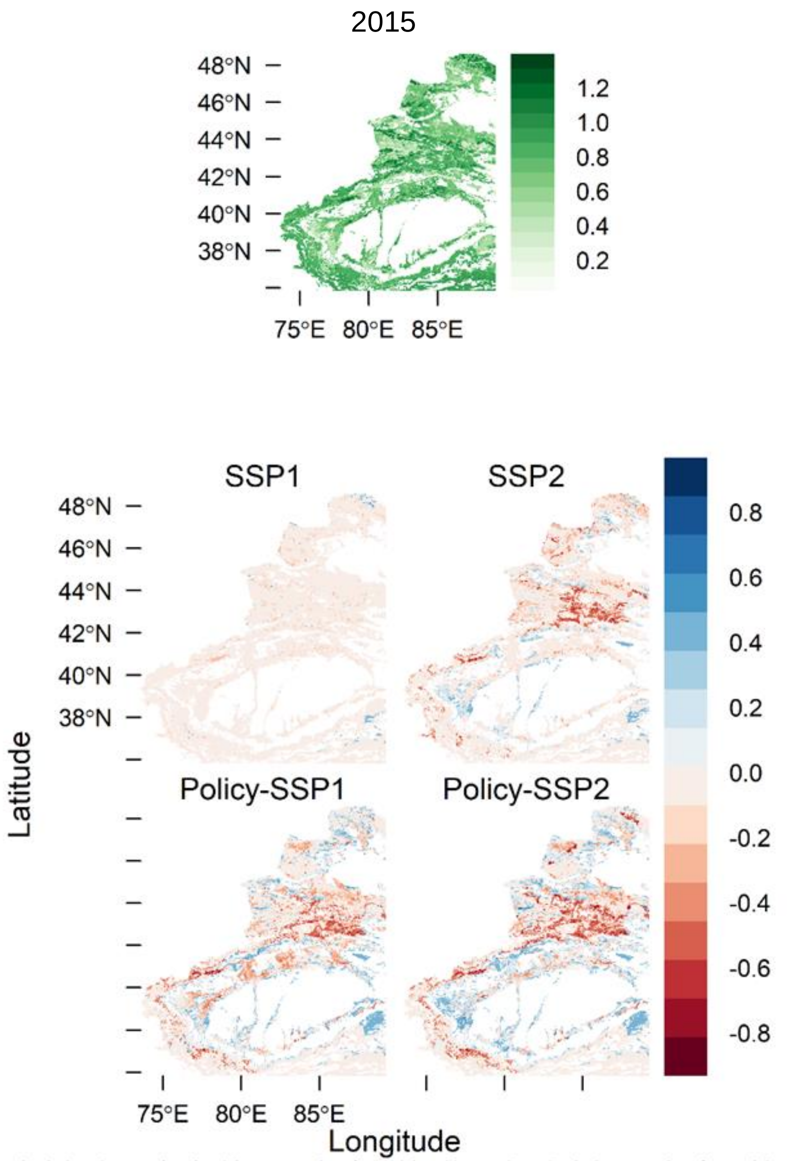

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Figure 21. Biodiversity intactness in 2015 (top panel) and changes to biodiversity intactness predicted by four scenarios within an arid region in the north-west of China (Region B).

In contrast to the other regions examined in closer detail, the mixed grassland and forests found in the south of China within Yunnan province see overall increases in biodiversity intactness with only limited areas of degradation (Region C; Figure 22). Here again, we see clear differences between the scenarios, with overall low increases in biodiversity forecast in SSP1, but more dramatic increases in biodiversity forecast in the policy enacted SSP1 scenario. SSP2 forecasts most of the region to regain biodiversity intactness, but with areas of loss along the southern perimeter. However, the policy enacted SSP2 scenario predicts much restoration of biodiversity in the southwest and northeast of the region, within the forested hills, but some degradation due to farming and urbanisation in the grassland areas through the centre of this region.

2015

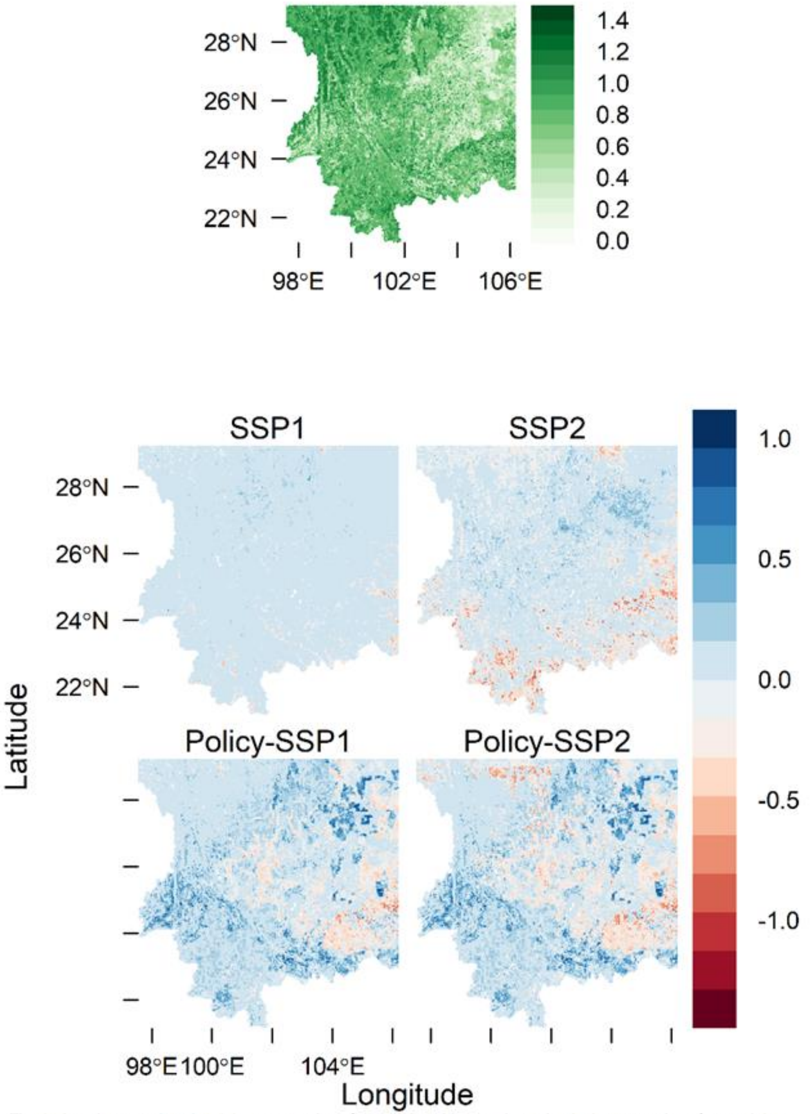


Figure 22. Biodiversity intactness in 2015 (top panel) and changes to biodiversity intactness predicted by four scenarios within a grassland region in the south of China (Region C).

In the predominantly agricultural region in central China shown in Figure 23 (Region D) the impact of the intensification of agriculture is clearly shown in our scenarios. Particularly in the policy enacted scenarios for SSP1 and SSP2, the agriculture in the central areas is intensified, leading to decreases in biodiversity intactness; however, even within this predominantly agricultural region, the losses are balanced by interspersed areas of restoration including a larger area of restoration in the north-western corner of this region. These patches of restoration within a wider field of agriculture area likely to be highly important to the region. Such remnant patches will likely provide important ecological services to the agricultural areas and will act as refuges for wild species.

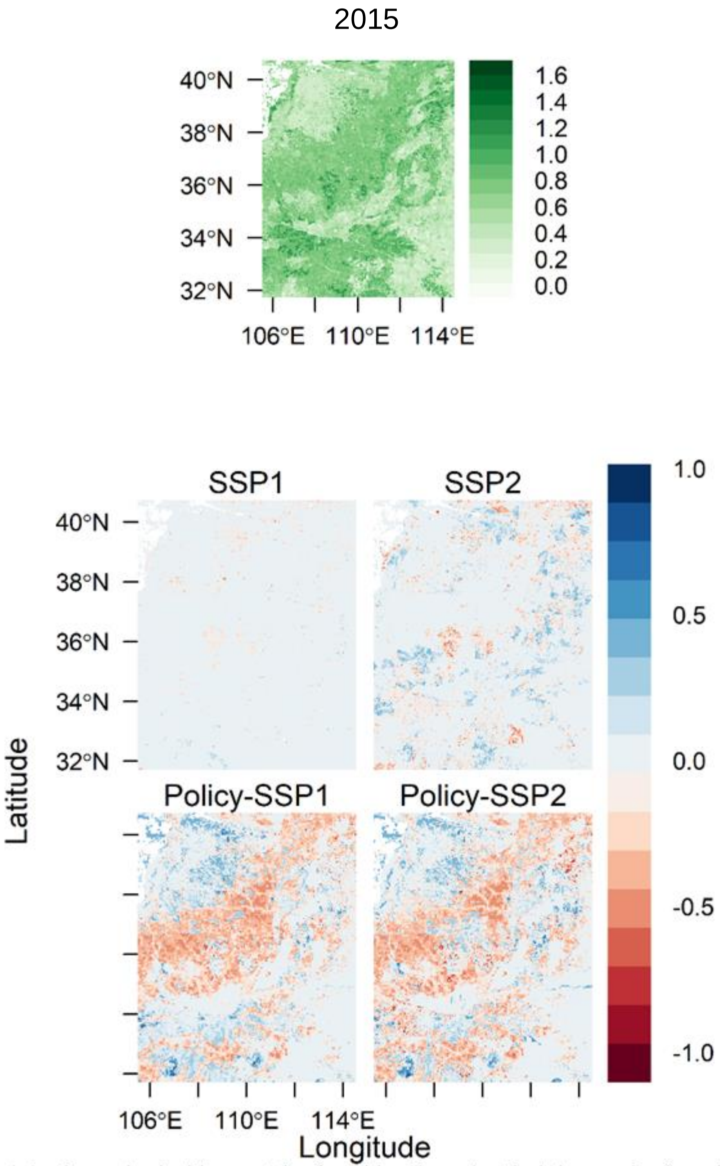


Figure 23. Biodiversity intactness in 2015 (top panel) and changes to biodiversity intactness predicted by four scenarios within an agricultural region in the centre of China (Region D).

3.6 Impacts on carbon stocks

Overall, the SSP1 scenario with policy enacted was the only scenario that forecast an increase in carbon stocks from 2015, with an increase of 4.77%, equivalent to a gain of 1,323 million tonnes of carbon overall, or an average of 66 million tonnes per year (Table 13). All other scenarios (baseline SSP1, SSP2 with and without policy targets), forecast decreases in carbon stocks of 3.3%, 14.77% and 1.25% respectively. For the baseline scenarios, this could be caused due to the reduction in overall natural habitat in both these scenarios compared to 2015. Although the policy enacted SSP2 has a forecasted increase in area of natural forests and grasslands, its large increase in intensive agriculture could explain the decrease in carbon stocks. Further, all scenarios have an increase in area of urban land due to population growth which is another factor for low carbon stock values.

However, these changes varied between biomes. For example, policy enacted SSP1 predicted a 36.33% increase in carbon stocks in the Deserts & Xeric Shrublands biome, but a 23.2% decrease in the Temperate Grasslands, Savannas & Shrublands biome (Table 13 and Figure 24, Figure 25, Figure 26).

The baseline SSP1 scenario forecasts decreases in carbon stocks in all biomes, as does the baseline SSP2 scenario (apart from in Deserts & Xeric Shrublands). In contrast, the SSP1 scenario with policy enacted projects that there will be increases in all biomes other than Boreal Forests/Taiga and Temperate Grasslands, Savannas & Shrublands. However, these are modest increases in terms of tonnes of carbon stock, as the increase in carbon stocks for China is estimated at 4.77%.

There were no biomes that saw increases under all scenarios. Boreal Forests/Taiga and Temperate Grasslands, Savannas & Shrublands are both estimated to decrease in carbon stocks within all scenarios. The decrease in carbon stocks in Temperate Grasslands, Savannas & Shrublands could be because the boundary of biomes is assumed to be constant even in future scenarios. Therefore, although the area of grasslands is increasing overall in China, other changes within this biome's boundary could cause the carbon stock values to reduce.

Within biomes, the Tropical & Subtropical Moist Broadleaf Forests are estimated to have a large increase (8.33%) in Carbon stocks with the SSP1 scenario with policy enacted. This area includes the Hainan Province, Guangdong province, southern parts of Yunnan province and eastern parts of the Qinghai-Tibet Plateau. Montane Grasslands & Shrublands biome are predicted to have the high losses (31.3%) in Carbon stocks with the baseline SSP2 scenario. This area covers large parts of Western China including most of Tibet, large parts of Qinghai province, north-west parts of Sichuan province and western edges of Xinjiang province.

It should be noted that our scenario analysis did not include other habitat types such as wetlands and peatlands. This is to reduce complexity and the volume of data that needed to be processed, considering constraint of the project scope. Although it is likely that the restoration actions we quantify would have positive consequences for wetlands it is also possible that the agricultural intensification would have negative consequences, and this would need to be addressed through further investigation.

Table 13. Carbon stock values per biome and % changes from 2015 for different future scenarios. Ecoregion ‘rock and ice’ which covers 51,312 km^2 is excluded.

Biome no.	Biome	Baseline (C stock in million tonnes)	SSP1		Policy-SSP1		SSP2		Policy-SSP2	
			(C stock in million tonnes)	(% change from baseline)	(C stock in million tonnes)	(% change from baseline)	(C stock in million tonnes)	(% change from baseline)	(C stock in million tonnes)	(% change from baseline)
1	Tropical & Subtropical Moist Broadleaf Forests	10,274.88	10,113.99	-1.57	11,131.15	8.33	9,200.70	-10.45	10,734.48	4.47
4	Temperate Broadleaf & Mixed Forests	8,033.63	7,837.58	-2.44	8,144.54	1.38	7,369.95	-8.26	7,862.30	-2.13
5	Temperate Conifer Forests	3,338.19	3,329.58	-0.26	3,559.82	6.64	2,578.55	-22.76	3,070.02	-8.03
6	Boreal Forests/Taiga	0.55	0.54	-1.87	0.39	-29.55	0.54	-1.87	0.38	-29.73
8	Temperate Grasslands, Savannas & Shrublands	1,079.35	928.07	-14.02	828.87	-23.21	801.21	-25.77	806.38	-25.29
9	Flooded Grasslands & Savannas	206.36	202.81	-1.72	214.88	4.13	189.50	-8.17	207.90	0.74
10	Montane Grasslands & Shrublands	4,367.20	4,015.14	-8.06	4,592.18	5.15	3,000.46	-31.30	3,954.26	-9.46
13	Deserts & Xeric Shrublands	416.89	375.27	-9.98	568.36	36.33	482.61	15.76	733.87	76.03
Total		27,717.04	26,802.98	-3.30	2,9040.19	4.77	23,623.51	-14.77	27,369.58	-1.25

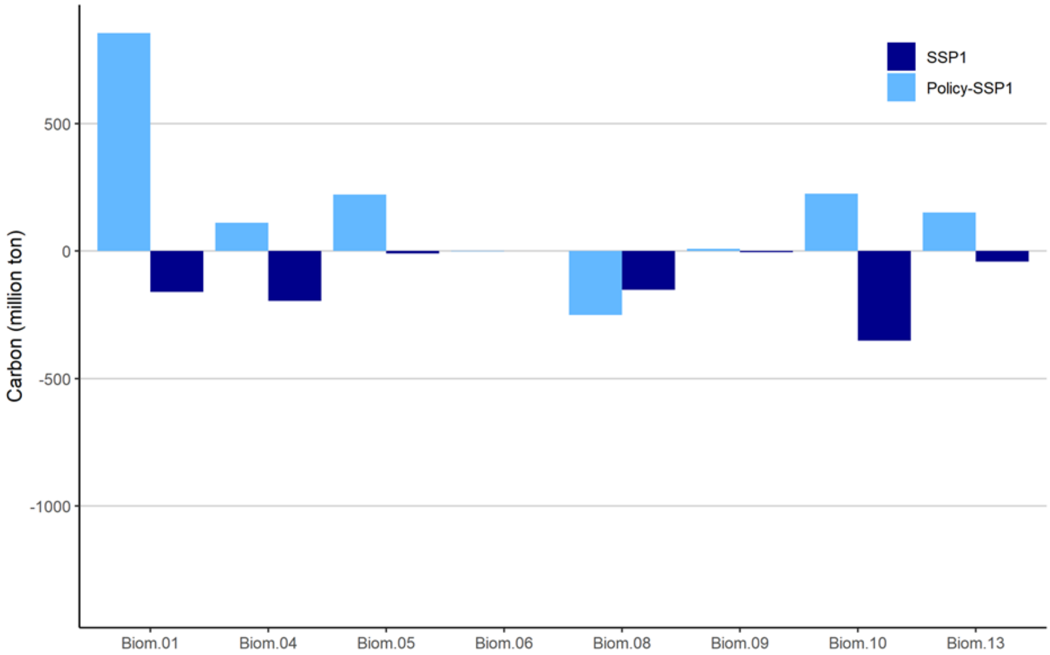


Figure 24. Change in carbon stocks from 2015 under SSP1 with and without policy targets, broken down by biomes. Biom 01 – Tropical & Subtropical Moist Broadleaf Forests; Biom 04 – Temperate Broadleaf & Mixed Forests; Biom 05 – Temperate Conifer Forests; Biom 08 – Temperate Grasslands, Savannas & Shrublands; Biom 09 – Flooded Grasslands & Savannas; Biom 10 – Montane Grasslands & Shrublands; Biom 13 – Deserts & Xeric Shrublands.

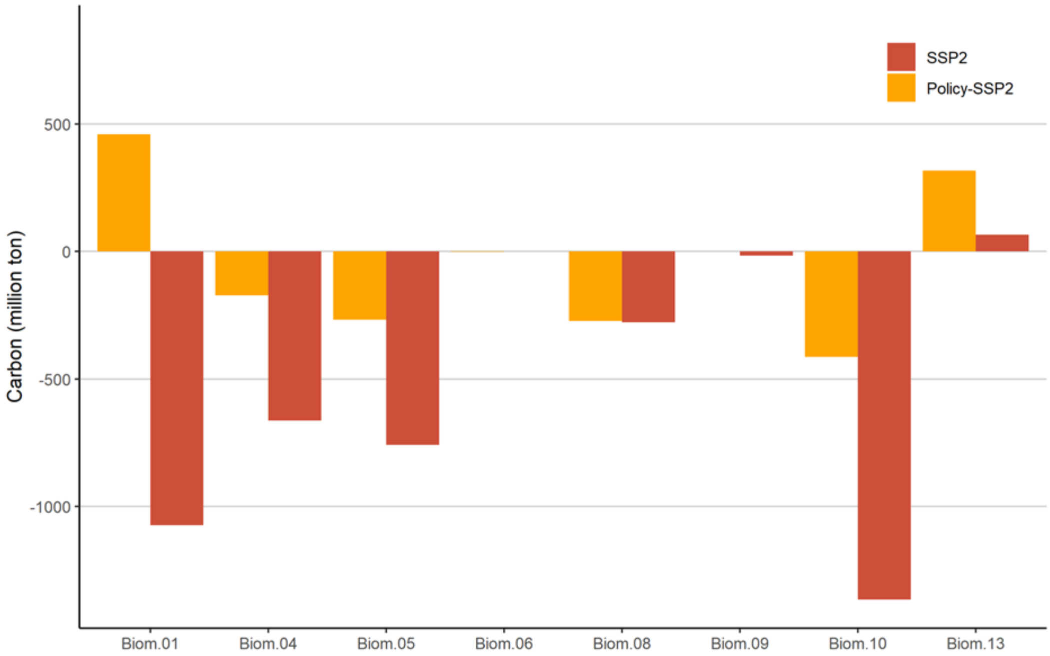


Figure 25. Change in carbon stocks from the baseline under SSP2 with and without policy targets, broken down by biomes. Biom 01 – Tropical & Subtropical Moist Broadleaf Forests; Biom 04 – Temperate Broadleaf & Mixed Forests; Biom 05 – Temperate Conifer Forests; Biom 08 – Temperate Grasslands, Savannas & Shrublands; Biom 09 – Flooded Grasslands & Savannas; Biom 10 – Montane Grasslands & Shrublands; Biom 13 – Deserts & Xeric Shrublands.

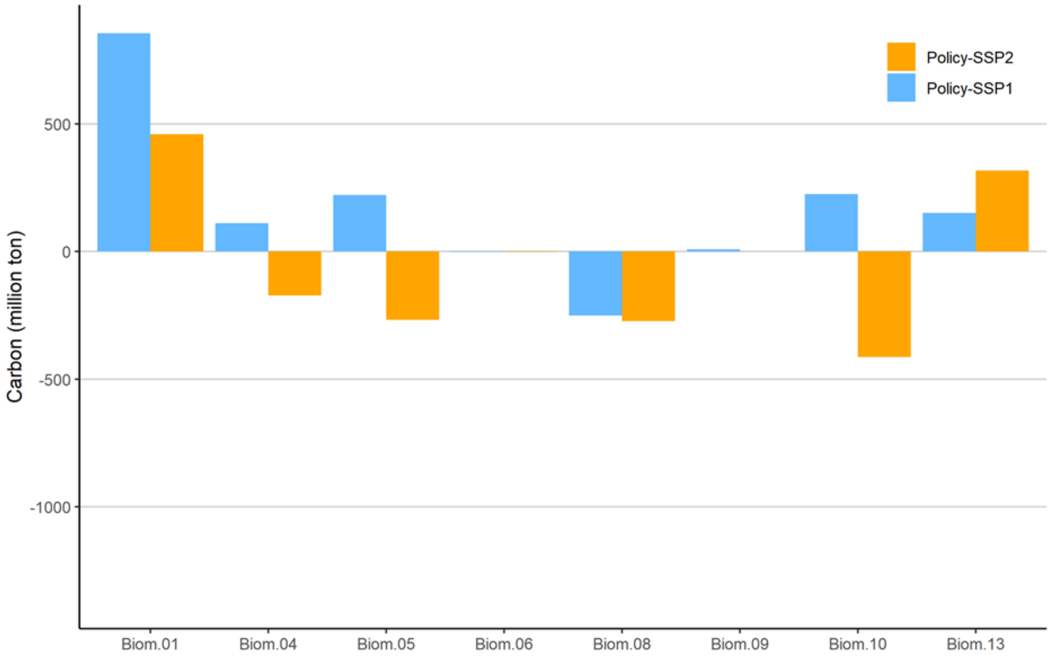


Figure 26. Change in carbon stocks from the baseline within the policy enacted scenarios of SSP1 and SSP2, broken down by biomes. Biom 01 – Tropical & Subtropical Moist Broadleaf Forests; Biom 04 – Temperate Broadleaf & Mixed Forests; Biom 05 – Temperate Conifer Forests; Biom 08 – Temperate Grasslands, Savannas & Shrublands; Biom 09 – Flooded Grasslands & Savannas; Biom 10 – Montane Grasslands & Shrublands; Biom 13 – Deserts & Xeric Shrublands.

Boreal Forests/Taiga and Temperate Grasslands, Savannas & Shrublands are both estimated to decrease in carbon stocks within all scenarios. There were no biomes that saw increases under all scenarios.

3.7 Conclusions

Our scenarios estimate likely futures based on two differing global socio-economic situations – encoded by SSP1 and SSP2 – with Chinese environmental policies (including increase of natural forests and grasslands and expansion of the protected area network, see Table 3) enacted or not. This allows us to explore the impact of the policies considering the uncertainty around differing direct and indirect socio-economic drivers.

Our scenarios estimate starkly different futures. The SSP2 baseline scenario (i.e., the SSP2 scenario without policy enacted) tends to be the least favourable of the four scenarios across our measures of biodiversity impact with losses forecast in forest and grassland driving overall decreases in species range sizes, biodiversity significance, and biodiversity intactness, as well as losses in ecosystem services including large losses in carbon stocks. This is not surprising as SSP2 describes a future where historical trends are continued, therefore an increased population must either live in areas of increasingly dense or enlarged urban areas, and, likewise, agricultural production either extensifies or intensifies to provide for increasing populations. This scenario demonstrates the urgent need for transformative change, as continuation along historical trendlines will only lead to further degradation of biodiversity.

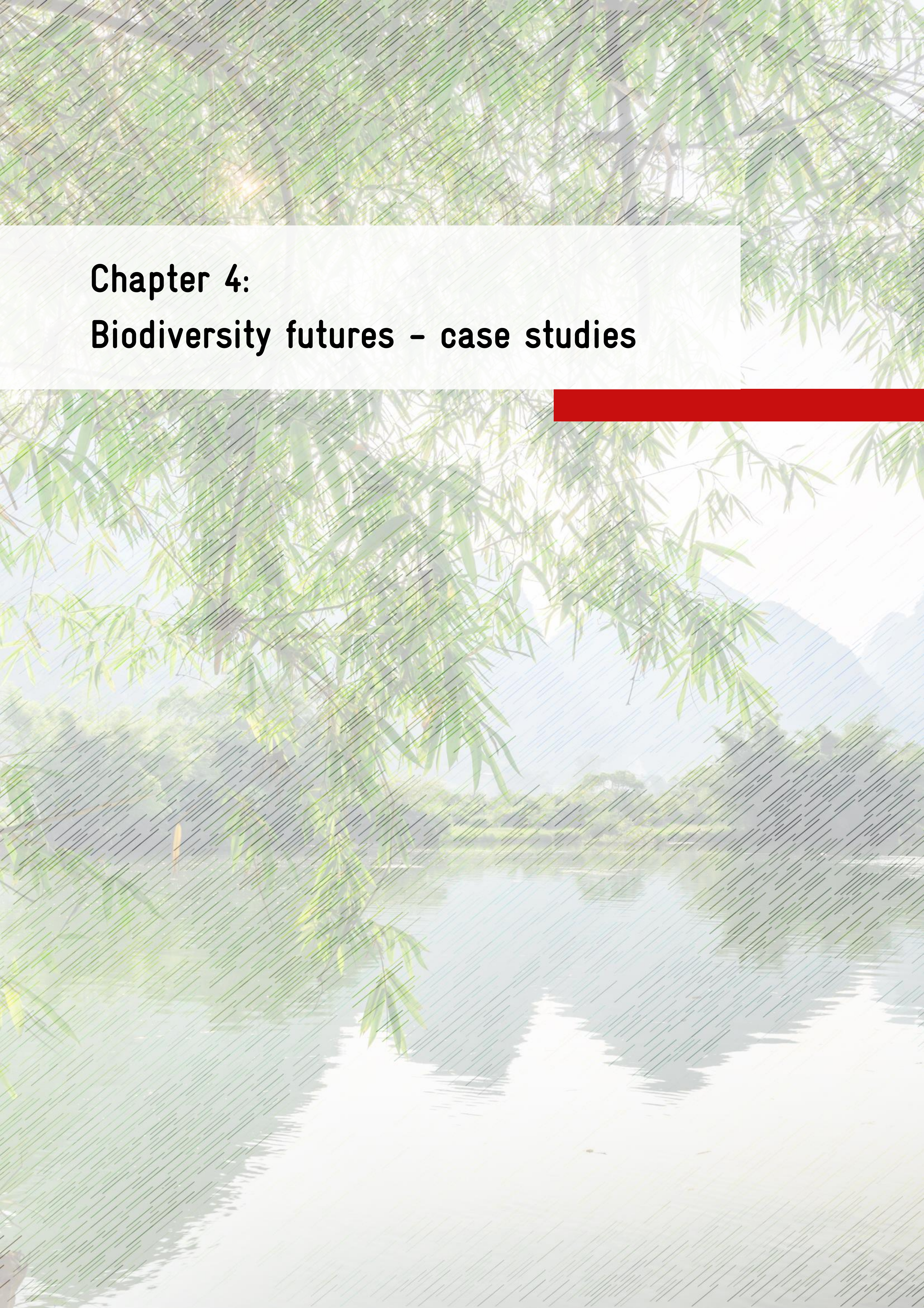
The comparison of the SSP2 baseline and SSP2 policy enacted scenarios reveals the difference that the implementation of China’s conservation policies will make (if other socio-economic factors continue to develop along historical trends). SSP2 Policy estimates that large areas of China can be converted to restored grassland and forest, and therefore a recovery in biodiversity within restored areas (particularly forecasting a reduction in overall species extinction risk and an increase in biodiversity significance and biodiversity intactness) is likely to occur.

The comparison of SSP2 policy enacted scenario and the SSP1 baseline scenario provides an interesting contrast of futures where efforts have been focussed on 1) the direct impacts of biodiversity loss but other drivers proceed along roughly historic trends (SSP2 policy enacted scenario) or 2) socioeconomic changes that mainly alter indirect drivers of biodiversity loss (SSP1 baseline scenario). For instance, SSP2 policy enacted scenario includes a focus on the restoration of large areas of forest and grasslands, but at the cost of intensification of nearby agriculture; whereas the SSP1 baseline scenario describes a future with little change in natural areas, but increased production through indirect measures such as minimisation of waste and technological advancement (thereby avoiding agricultural intensification or extensification). The comparison here is nuanced. At a national scale, SSP1 shows little change in biodiversity, which is still a positive result given that production has increased, with only small amount of change in natural area extent, biodiversity intactness, and carbon storage, and both losses and gains in species ranges. SSP2 policy enacted describes much land use change with the highest area of both agricultural intensification and forest restoration of all scenarios. While in SSP1 most of the natural areas remain untouched, in this scenario the location of agricultural production is optimised for climatic conditions, leading to loss of natural areas as well as gain (resulting in overall gain). This results in those metrics that do not consider age of restoration, such as biodiversity significance, estimating more positive results for SSP2 policy enacted than SSP1 baseline. However, those metrics that do consider age of restoration, such as biodiversity intactness, estimate more positive results for SSP1 baseline than for SSP2 policy enacted.

SSP1 Policy forecasts the most positive biodiversity results when compared across all scenarios. This scenario includes large-scale restoration and conservation, but agricultural intensification, while present, is not as widespread as SSP2 Policy as demand in production is minimised through actions such as change in diets and improved waste management, while production is increased through technological advancement in sustainable agricultural management. In this scenario, urban areas expand, but expansion occurs through the introduction of suburban low intensity development. Agricultural areas are optimised, but not at the expense of natural areas. And throughout China, large areas of grassland and forest are restored. The preservation of natural areas results in many narrow-ranged species maintaining or increasing their ranges. When analysing across all species considered, this scenario forecasts large gain in species' ranges (nearly one third of species expand their habitat range by at least 30%) and overall biodiversity significance and is the only scenario that does not predict the extinction of any species. It also forecasts the greatest increases in carbon storage of any scenario, despite the loss in plantation forest area which are often positive for carbon storage but harmful to biodiversity. When considering the state of biodiversity when restored areas are allowed to mature, SSP1 Policy scenario also provides the most optimistic results for overall biodiversity intactness. Biodiversity intactness is one of the most sensitive measures, picking up on small changes in the relative make-up of species communities, and therefore is sensitive to the means of restoration applied. In our models, we conservatively assume passive restoration, but if restoration is active (i.e., mature trees are planted, species are reintroduced, or conservation management is applied) then it is likely that results will be positive.

Chapter 4:

Biodiversity futures - case studies



4 Biodiversity futures – case studies

Here we examine two case studies, allowing us to go into more detail on the potential outcomes of the scenarios. The first case study is the charismatic giant panda, chosen as they are an icon of conservation efforts in China. The second is the island of Hainan, which was chosen because the island is extremely biodiverse with many endemic species. We examine in more detail the potential effects of the scenarios on connectivity, forest change, carbon stocks and tourism.

Credit: Yoreh – stock.adobe.com

4.1 Summary

In this chapter we focus on two case studies to illustrate what may be achieved at a more specific level, with the implementation of China's environmental policies. The first case study focusses on a specific species, the giant panda, and the second on a specific area, Hainan Island.

Our results showed that giant panda populations are likely to decline if environmental policies are not enacted and socioeconomic conditions follow a business as usual path. This was due to the conversion of giant panda habitat to pasture. However, the enactment of environmental policies resulted in both an increase in giant panda habitat area and connectivity which are likely to result in increases in giant panda population sizes. Our results demonstrated not only how much habitat could be restored or protected for giant pandas, but also where restoration could be most effectively planned to enable giant pandas to move between habitat patches.

Hainan Island is an important site for biodiversity within China, hosting many rare and endemic species adapted to its forested and coastal environments. However, the biodiversity of Hainan Island is under threat from agricultural development and exploitation of wild populations. Our work revealed dramatic differences in the area of forest forecast under the different scenarios. Without environmental policies, we predict a further decline in forest area within Hainan Island, with up to a 23% loss of forest by 2035. In contrast, the enactment of environmental policies led to restoration of large extents of forest, up to a 170% increase in the 20 years of our study. Our results pinpoint where in the Island forests could be restored to maximise forest connectivity, and how biodiversity, as well as the services provided by biodiversity such as carbon storage and ecotourism, and likely to benefit.

4.2 Case study # 1: Giant pandas

The giant panda (*Ailuropoda melanoleuca*) is one of the most well-known icons of conservation effort globally. Its range once stretched across much of China, northern Myanmar and Vietnam, but was drastically reduced by climatic changes in the Pleistocene. The giant panda's modern range has been further reduced due to anthropogenic impacts, such as agricultural expansion and forest loss (Huang et al., 2020). Their remaining habitat is extremely fragmented with poor connectivity (Wang et al., 2014).

In 2016, after years of conservation efforts, including protected area establishment and a reduction in poaching, the giant panda was downgraded from 'endangered' to 'vulnerable' on the IUCN Red List of Threatened Species (Swaisgood, R., Wang, D. & Wei, 2016). However, with only around 1,864 individuals left in the wild (Ministry of Ecology and Environment (MEE, 2018)) they are still at risk due to further habitat fragmentation and lack of connectivity (Bu et al., 2021).

4.2.1 Connectivity analysis

Here we look at likely futures for giant panda conservation and survival through an analysis of how the connectivity of the giant panda's habitat may be impacted by actions explored in the scenarios, both at a landscape and a habitat patch level.

4.2.1.1 Landscape

At a landscape level, three of the four scenarios (all except SSP2 baseline) projected an increase in habitat area and equivalent connected area (ECA) for giant pandas compared to 2015. Whereas the SSP2 baseline scenario, the business as usual scenario, predicted a serious decline in ECA (Figure 27). The ECA increased the most in SSP1 Policy, with an estimated increase of 22%, while SSP2 Policy was not far behind with an estimated increase of 20%. The SSP1 baseline scenario forecasted an increase in ECA of 7% and in the baseline SSP2 the ECA decreased by 43%, roughly twice as much as the largest increase, compared to 2015. The analysis suggests that SSP1 baseline, and policy enacted scenarios of SSP1 and SSP2 may all benefit giant pandas in terms of the amount of habitat available and the connectivity within the landscape. In contrast, it suggests SSP2 baseline scenario may have a large negative impact on the connectivity of the landscape for giant pandas.

For all scenarios, the change in ECA was estimated to be larger than the change in habitat area (Figure 27). The scenarios predicted to show positive change (SSP1 with and without policy targets, and SSP2 baseline), suggest that the habitat patches become less isolated under such conditions. This can either be due to the new habitat joining smaller patches together into larger patches, or the new habitat acting as stepping stones between isolated patches. For SSP2 baseline scenario, the larger expected decline in ECA than that in habitat area suggests that the loss of habitat is making the patches more isolated.

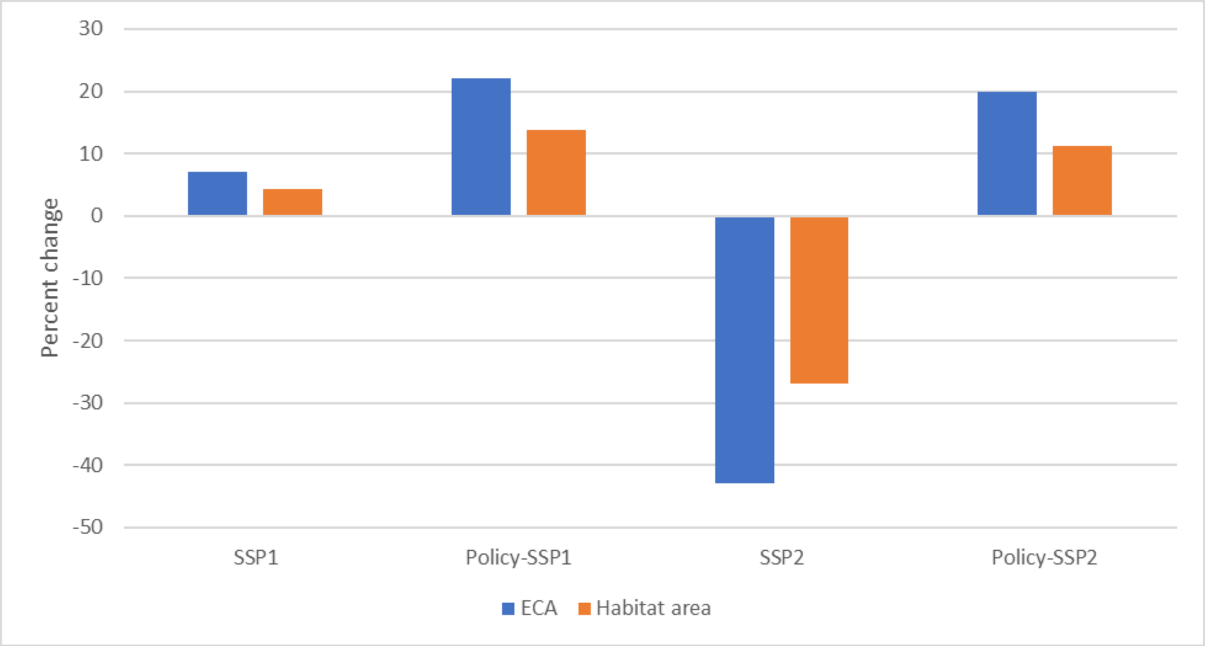


Figure 27. Percentage change in ECA and habitat area compared to the baseline across the four scenarios.

4.2.1.2 Patch level

In 2015 there were two large habitat patches which have a high contribution to the network's connectivity, in comparison to the rest of the patches in the landscape (Figure 28). The greater contribution of these patches is largely due to their size as there is more connected habitat in large patches than small patches. Current giant panda habitat is highly fragmented with low connectivity (Wang et al., 2014). Therefore, when we say high contribution to connectivity, this is in comparison to other habitat patches in the landscape and does not necessarily indicate overall high connectivity.

The largest change from 2015, at a habitat patch level, are forecasted under SSP2 baseline scenario where there is a reduction in habitat patch size and consequentially a reduction in their contribution to the connectivity of the landscape (Figure 27). Here, most of the giant panda habitat is predicted to be broken up into small, poorly connected patches. The resistance layer for SSP2 baseline scenario highlights the lack of suitable habitat between patches that would enable movement. This is a result of much of the forest within the giant panda's landscape predicted to be converted to grazing under this scenario.

There is an estimated increase in the contribution to connectivity for some habitat patches in the SSP1 scenarios (baseline and Policy), and SSP2 Policy, but not a substantial one given the potential new habitat available, especially within the policy enacted scenarios of SSP1 and SSP2. Only forest within the panda's current range was included as habitat patches. If the giant pandas were to expand their range into the new areas of forest predicted to be restored within the policy enacted scenarios of SSP1 and SSP2 currently outside their range, it may help to create larger and more connected patches. Such expansion would depend on these forests providing suitable habitat, including with the bamboo on which giant pandas depend.

Policy enacted scenarios of SSP1 and SSP2 forecast large increases of forest in and around the giant pandas remaining range. If these new forests included the bamboo understory the pandas require, this could improve the connectivity of the remaining giant panda habitat patches, and potentially enable them to expand their range.

In contrast, under SSP2 baseline scenario the giant panda's habitat is predicted to become even more fragmented, with smaller and less connected patches, mostly surrounded by agriculture and grazing with little connecting forest.

Additional understanding of dispersal of giant pandas and the barriers to dispersal may change the data and results (see also Chapter 2). However, we performed a sensitivity analysis with dispersal distances 10 km and 20 km either side of the dispersal distance used in these results (34 km), and the results all predicted the same pattern as the dispersal distance originally used.

We also assume that all forest area (below 4100 m) within a 50 km buffer of the giant panda's range is suitable, which may not be the case if areas lack bamboo. Climate change is predicted to cause shifts in available bamboo habitat (Fan et al., 2014; Songer et al., 2012; Tuanmu et al., 2013) which is not captured in our analysis. However, the ongoing effects of climate change on giant pandas and their habitat remains uncertain (Wang et al., 2021).

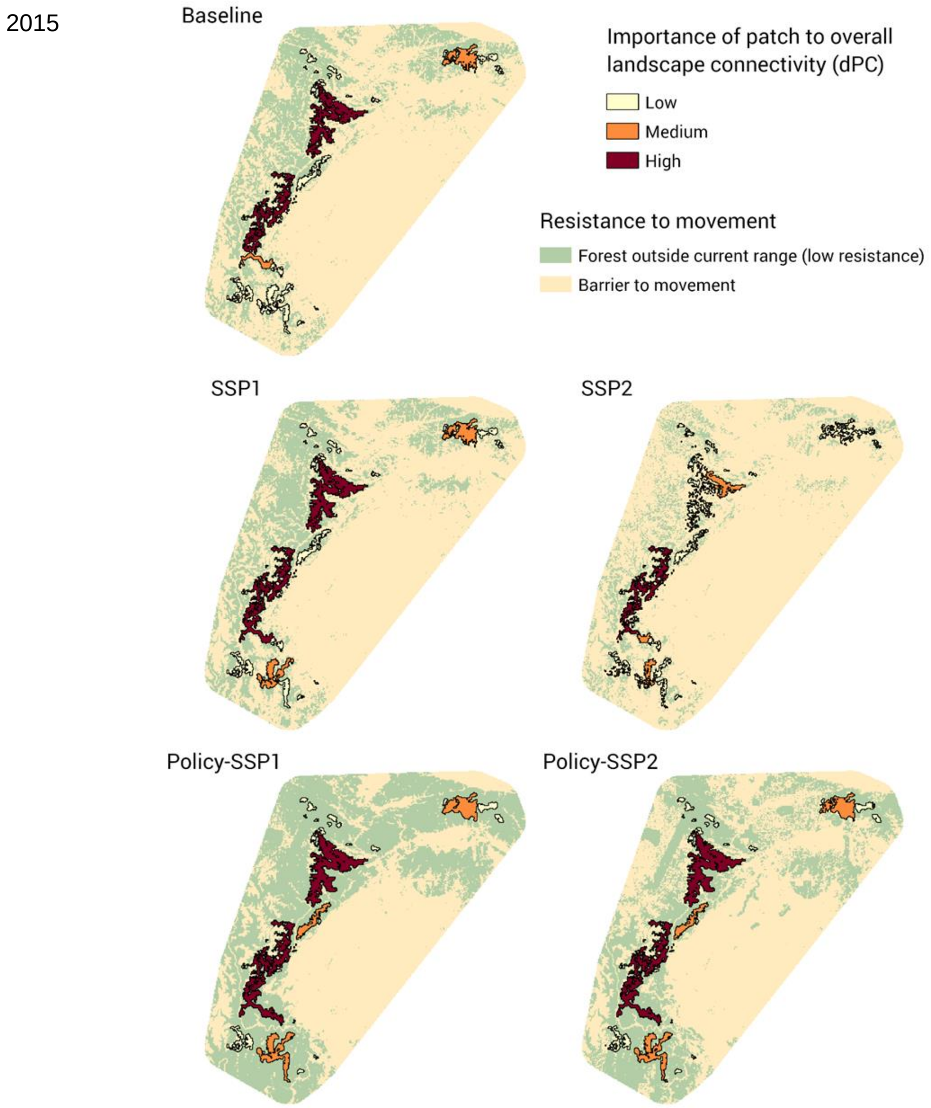


Figure 28. Giant panda habitat patches, within their current range (top), and predicted by four scenarios, coloured by the importance of the patch to the overall landscape connectivity. The resistance layer for each scenario is also displayed underneath. The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

4.3 Case study #2: Hainan Island

Hainan Island is highly biodiverse with many endemic species, including 397 endemic plants (Francisco-Ortega et al., 2010). The island is important for forest dependant species (Hill et al., 2019). It is part of the Indo-Burma biodiversity hotspot (Myers et al., 2000) and includes one of the 200 priority ecoregions for global conservation: the Hainan Island monsoon rain forests (Olson and Dinerstein, 2002). However, Hainan Island has seen substantial loss and degradation of forest, due to conversion to plantations and degradation by slash-and-burn cultivation (Figure 29 top panel). This, along with hunting, has led to many species on the island becoming threatened with extinction (Zhai et al., 2015; Zhang et al., 2000).


Credit: Pavel Roev – stock.adobe.com

4.3.1 Forest change

Within the policy enacted scenarios of SSP1 and SSP2, large increases in forest cover are projected on Hainan Island (Figure 29). Increases are estimated from 8,300 km² in 2015 to 22,420 km² (170% increase) and 19,220 km² (132% increase) by 2035 under the policy enacted scenarios of SSP1 and SSP2 respectively. A small decrease in forest cover is predicted to occur under the SSP1 baseline scenario (1%), and a large decrease of 1892 km² under the SSP2 baseline scenario (23%). The large increases of natural forest projected under the policy enacted scenarios of SSP1 and SSP2 are predicted to occur across the central and southern areas of the island (Figure 29).

The increase projected in forest within the policy enacted scenarios of SSP1 and SSP2 is mainly in areas that were agricultural land systems in 2015. This could have large benefits for biodiversity on the island, as well as resulting in increases of carbon stocks. The forest loss projected under the SSP2 baseline scenario largely occurs in areas of grass-forest mix system as of 2015, turning into grazing under the SSP2 baseline scenario.

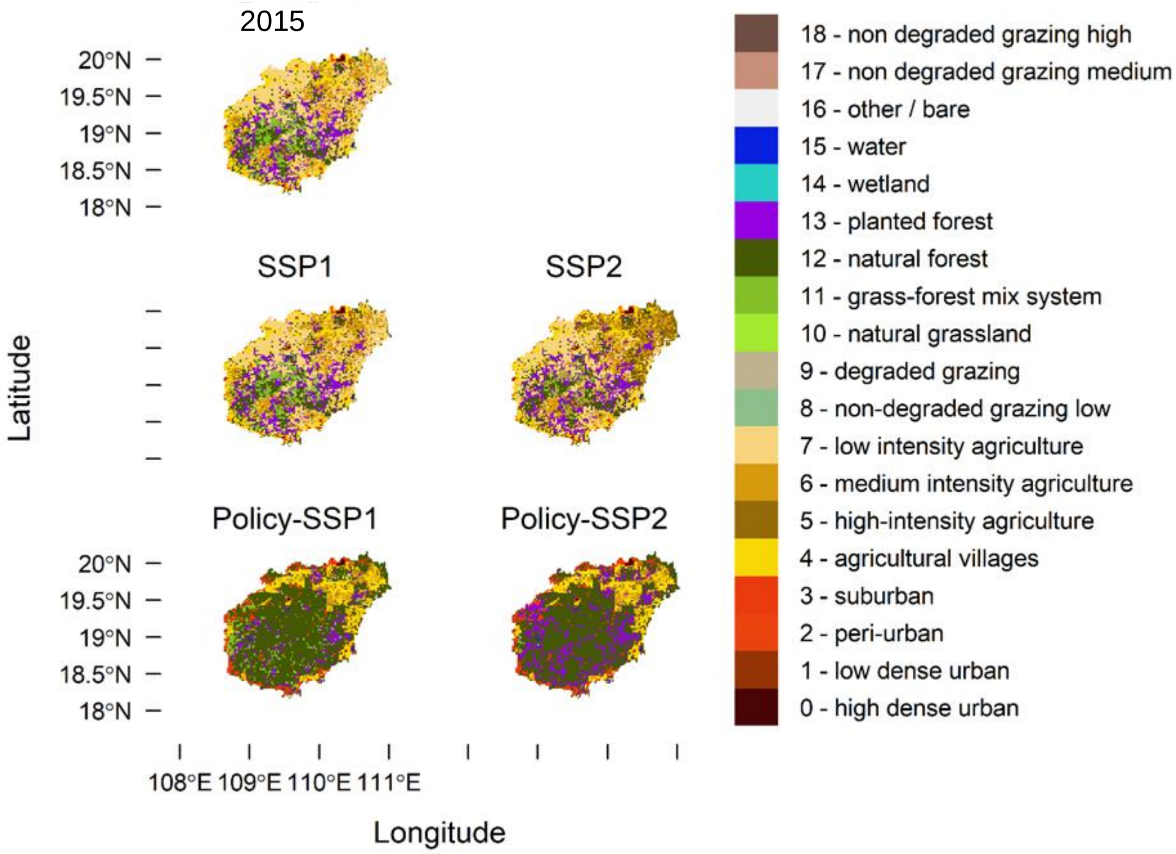


Figure 29. Pattern of land use on Hainan Island in the current day (top panel) and predicted by four scenarios.

4.3.2 Forest connectivity

Given the large increases and decreases estimated in forest cover under the different scenarios, and as the forest on Hainan Island is critical to support biodiversity, we looked at how these changes may impact forest connectivity on both a landscape and habitat patch level.

4.3.2.1 Landscape level

The results forecast similar trends in the generalist and specialist species groups across the scenarios (Figure 30 and Figure 31). Under the policy enacted scenarios of SSP1 and SSP2 there are substantial increases predicted in natural forest which results in large increases in ECA for all dispersal distances for both specialists and generalists. These range from a 175% increase in ECA from 2015 for generalists at a 25 km dispersal distance in the SSP2 policy scenario to a 426% increase for specialists at a 5 km dispersal distance in the SSP1 policy scenario.

Within the policy enacted scenarios of SSP1 and SSP2, larger increases were projected in ECA than the increases in habitat area. Under SSP1 Policy the habitat area is forecasted to increase from 2015 by 170%, and under SSP2 Policy it is forecasted to increase by 132%. The larger increases expected in ECA than habitat area within the policy enacted scenarios of SSP1 and SSP2 are due to the incorporation of many small, isolated patches in 2015 into several large patches in these two scenarios.

Under the baseline scenario of SSP2 there is a projected decrease in ECA from 2015, ranging from a 34% decrease for generalists at a 25 km dispersal distance to a 54% decrease for specialists at a 5 km dispersal distance. The habitat area under the SSP2 baseline scenario is projected to decrease by 23%, also showing a smaller decrease in habitat area than the decrease in ECA. This is due to the remaining habitat patches in 2015 being further broken up into smaller, fragmented patches under the baseline scenario of SSP2.

The forest on Hainan Island was already greatly reduced and fragmented in 2015, and under the baseline scenario of SSP2 this fragmentation is predicted to get worse. However, the policy enacted scenarios of SSP1 and SSP2 predict that the connectivity of the landscape could improve greatly with large areas of forest restored across the central and southern parts of the island. Whilst under the baseline scenario of SSP1, there would be little change.

Policies aimed at restoring forest could therefore greatly benefit biodiversity by increasing the habitat area of species, as well as improved connectivity between forest patches. The increase in connectivity may also enable species to recolonise areas where they have currently been lost. However, this is something that would likely take many years, with some species being able to disperse quicker than others. The quality and maturity of the new habitat would also play a role in the ability of species to move into new areas (Bailey, 2007). As well as restoring forest, policies aimed at conserving the remaining forest are also very important. Losing more forest will likely fragment the habitat further, with the loss of some patches having more of an impact than others. Such decreases in connectivity could lead to the loss of endangered endemic species.

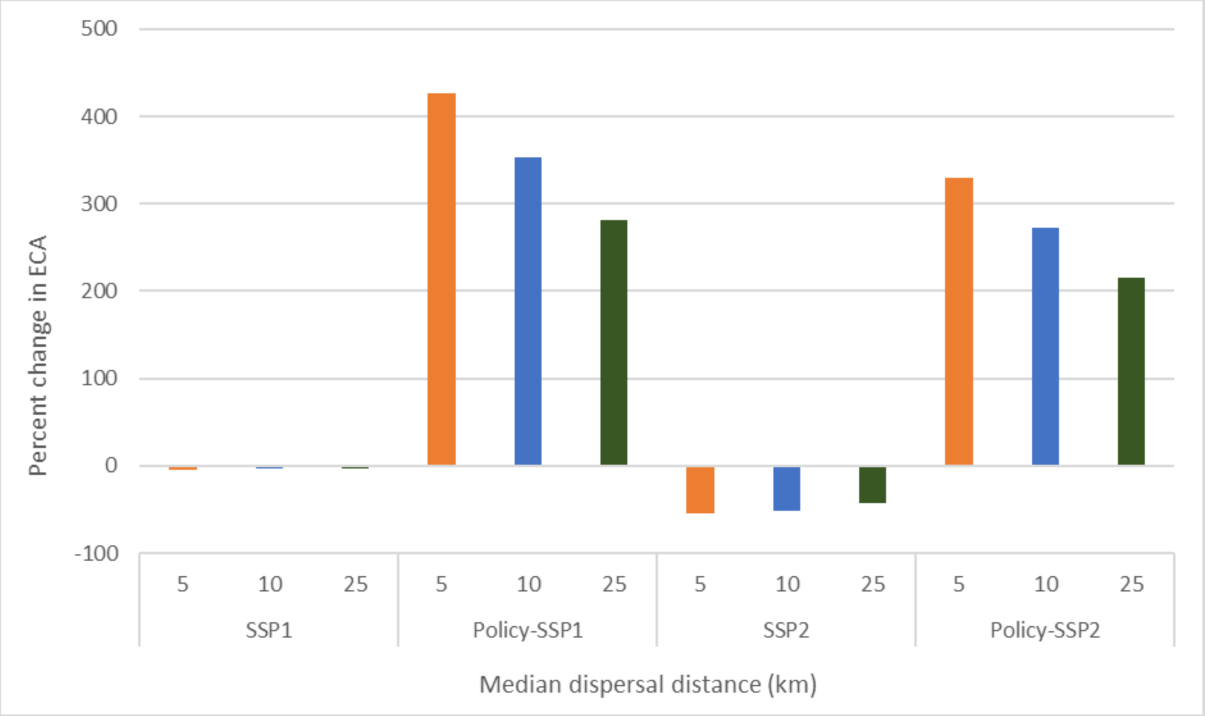


Figure 30. Percentage change in ECA predicted by four scenarios for specialist species at 5, 10 and 25km median dispersal distances.

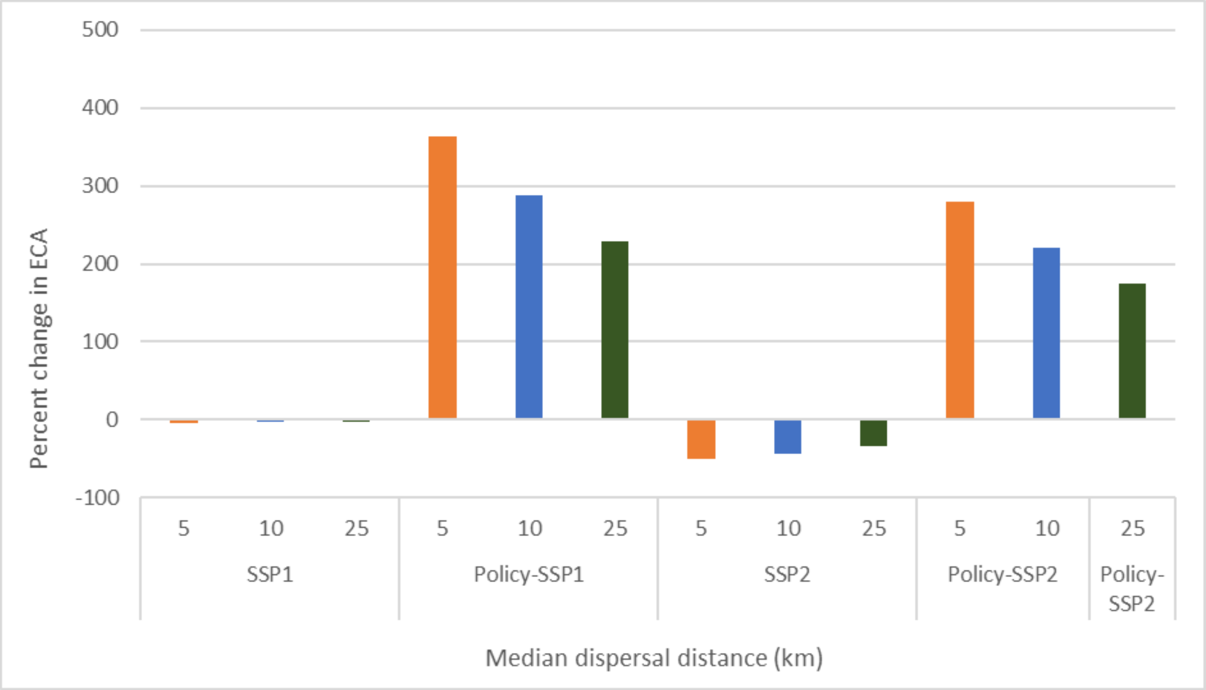


Figure 31. Percentage change in ECA predicted by four scenarios for generalist species at 5, 10 and 25km median dispersal distances.

4.3.2.2 Patch level

In 2015 there was one large patch of forest (2100 km²) surrounded by many small, isolated patches. This large patch has a relatively high contribution to the connectivity of the landscape, whereas most of the other patches have a very low contribution for all dispersal distances of specialists and generalists. The patterns under the different scenarios at a patch level were similar for generalists and specialists, as they were at the landscape level, with the shorter dispersal distances and specialist species projecting slightly more change (both negatively and positively). Therefore, we only show specialists at 5 km in Figure 32, as they are the most impacted group.

Under the policy enacted scenarios of SSP1 and SSP2, there are dramatic increases projected in forest area that result in a large central forested patch (18,572 km² and 14,964 km² respectively) with a high contribution to the connectivity of the landscape (Figure 31). The smaller patches of forest in the north-east of the island in these two scenarios still contribute little to the connectivity of the landscape as they are separated from the large patch by areas of agriculture.

There is loss of forest estimated for the baseline scenario of SSP2, creating smaller, less connected patches. This is largely due to expansion of grazing into forested areas. Whilst under the baseline scenario of SSP1, it is estimated to be little change.

The resolution of the land systems data (2 km²) meant we were unable to include short dispersal distances, such as 100 m and 1 km, in this analysis as have been used in other studies in the region (Wang et al., 2021). However, the forest gain projected under the policy enacted scenarios of SSP1 and SSP2 combines smaller fragmented patches in 2015 into one large patch which will likely have even greater benefits for short dispersal species than the species groups used in this analysis. Conversely, fragmentation of the habitat patches forecasted in the baseline scenario of SSP2 will have detrimental impacts on species with shorter dispersal capabilities.

The increase in forest area and connectivity in Hainan Island projected under the policy enacted scenarios of SSP1 and SSP2 could have large benefits for forest dependant species. One species that may benefit is the critically endangered Hainan gibbon (*Nomascus hainanus*). They are the world's rarest primate and possibly the world's rarest mammal species (Bryant et al., 2015). It is under threat due to habitat loss and hunting (Geissmann and Bleisch, 2020). Other endemic threatened species such as the Hainan Gymnure (*Neohylomys hainanensis*), Hainan Partridge (*Arborophila ardens*), Hainan Magpie (*Urocissa whiteheadi*) and Hainan Leaf-warbler (*Phylloscopus hainanus*) would also benefit from policies aimed at forest restoration and conservation.

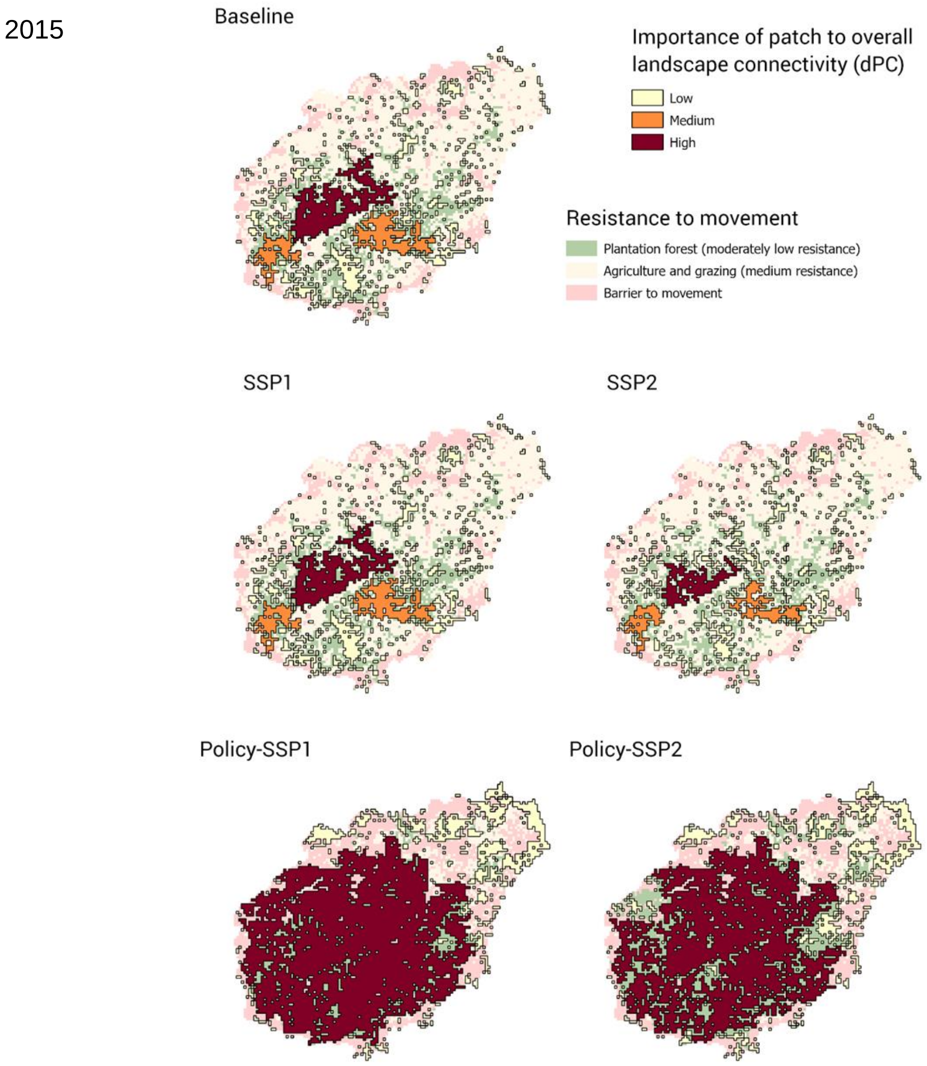


Figure 32. Forest patches on Hainan Island in the current day (top panel) and the four scenarios showing the importance of each patch to the overall landscape connectivity for specialist species (the more important the darker) with a median dispersal distance of 5km. The resistance layer for each scenario is displayed underneath. The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

4.3.3 Changes to carbon stocks

The reforestation of Hainan Island may have indirect benefits to biodiversity beyond the direct impacts of habitat restoration through the regulation of climate (both local and global) via carbon sequestration. When estimating carbon stock changes, the policy enacted scenario of SSP2 saw the greatest forecasted increase, with an increase of nearly 35% in carbon stocks compared to 2015. There was an increase of 12% projected under the policy enacted scenario of SSP1 and a small increase of 0.3% under the baseline scenario of SSP1. In contrast, under the baseline scenario of SSP2 there was a projected decrease of 3% in carbon stocks (Figure 33). The predicted increase in carbon stocks in the policy enacted scenarios was mainly in the central and southern areas of the island where forest is projected to increase.

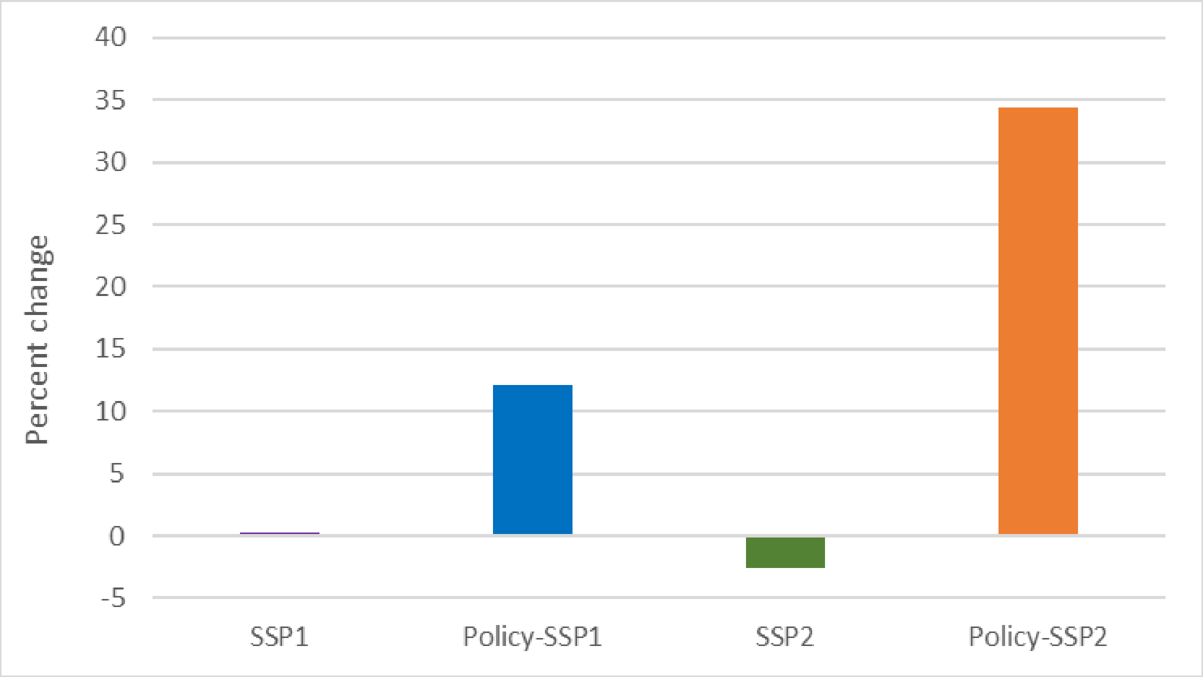


Figure 33. Percent change in carbon stocks predicted by the four scenarios.

The increase of carbon stocks projected under the policy enacted scenario of SSP2 was due to the restoration of degraded areas to natural forest, but also an increase in planted forest. In the Global Ecological Zone where Hainan Island is located, planted secondary forest > 20 years old has roughly twice the amount or carbon stocks per square kilometre than natural forest (whether pristine or newly restored). Therefore, under the policy enacted scenario of SSP1, even though there is a greater expected increase in natural forest than in SSP2 policy enacted scenario, there are lower projected overall carbon stocks as there is a decrease in planted forests. Figure 34 shows the dramatic increase in carbon stocks forecasted within the policy enacted scenarios of SSP1 and SSP2, with the greatest volume of carbon stock expected in the SSP2 policy enacted scenario in areas of planted forest.

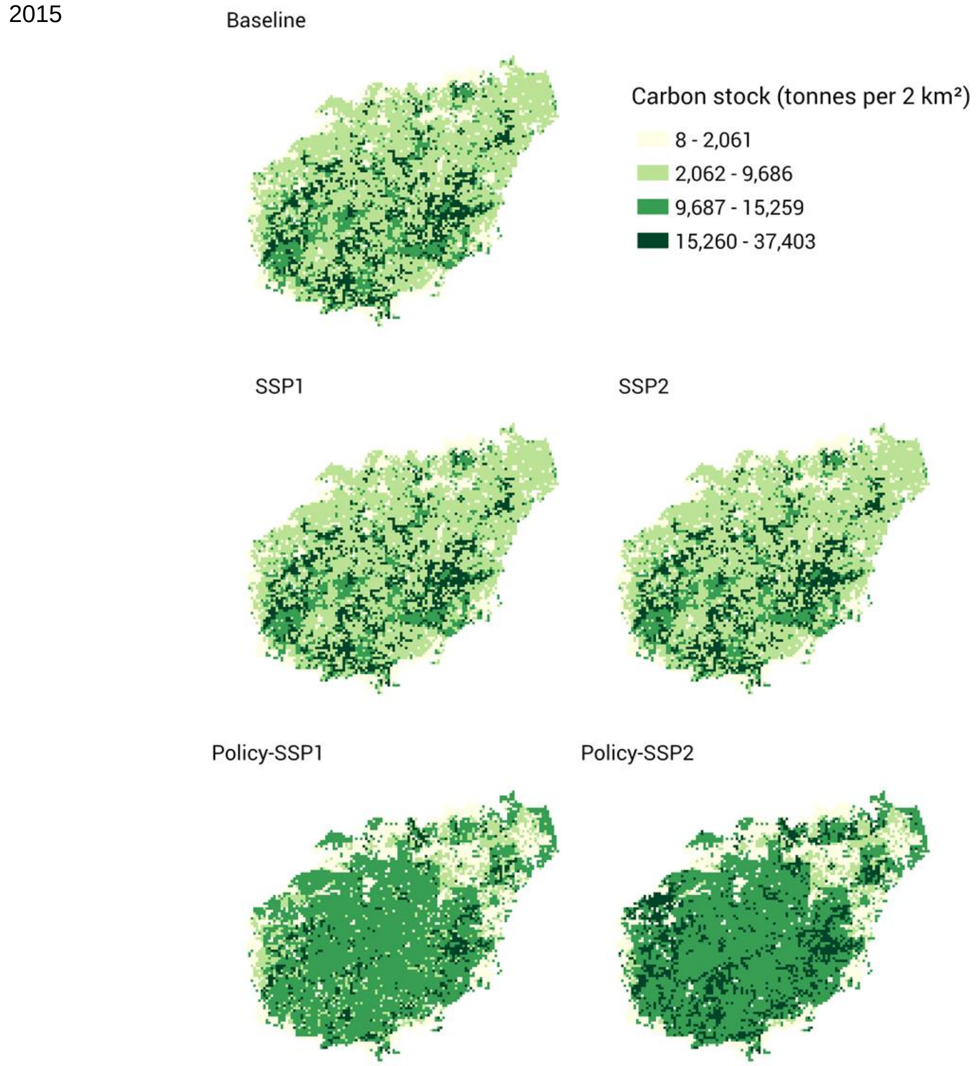


Figure 34. Patterns in carbon stocks on Hainan Island in the current day (top panel) and predicted by the four scenarios. The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

4.3.3.1 Tourism opportunities

Hainan is a popular tourist destination, mainly attracting domestic tourists (Stone and Wall, 2004). Tourism forms an important part of the island's economy, accounting for around 20% of the GDP (Hainan Provincial Bureau of Statistics. Hainan Statistical Yearbook, 2020; Zhang and Ju, 2021). Most of the tourism occurs in coastal areas, with economic opportunities from tourism more limited inland (Stone and Wall, 2004).

The large increase in forest in Hainan projected within the policy enacted scenarios of SSP1 and SSP2 potentially presents ecotourism opportunities. These projected increases in forest may in turn benefit biodiversity leading to additional ecotourism benefits. Ecotourism can be a lucrative source of income for local communities, whilst at the same time providing an incentive to protect biodiversity. Often substantial start-up costs are incurred, for example, for accommodation construction (Di Sacco et al., 2021), but there are encouraging signs that ecotourism could play an important part in Hainan Island's tourism industry. For example, at a recent speech given by President Xi Jinping in Hainan in April 2022, he re-emphasized the strategic, overarching plan for the island[14]. Within this plan, building the island into a national ecological civilisation pilot and an international tourism consumption centre were highlighted as two of the four goals that lead Hainan's future development. Ecological environment protection was raised as one of the eight pillars approaches in support of the realisation of these goals. Under this 'ecological environment protection pillar', various focal areas were emphasised, including pollution control, national park, blue economy and enhancing ecological environment in support of eco-tourism. On Hainan Island's official tourism website (English version[15]) over 20 nature parks are listed as key tourist attractions; tourists are encouraged to visit the parks and experience the unique biodiversity within Hainan's forests, but many other activities are also offered including ziplining, nature trails, waterfall experiences, camping, climbing, and stays in forest cabins. Post-covid recovery for its tourism sector is a key focus for Hainan. In addition to long-term plans guided by the "Effectively coordinate epidemic prevention and control and economic and social development" released by the Hainan Provincial government, there are also various short-term and very focused plans to help the recovery of this sector. For example, in May 2022, the Hainan Provincial Department of Tourism, Culture, Radio, Film, Television and Sports released "the unconventional measures to promote the recovery and revitalization of the tourism industry", with the aim to boost its tourism sector in the next three months[16].

Reforestation may also offer other economic opportunities. Hainan is known for its indigenous peoples and culture. Traditionally made products sourced from the forests may provide economic benefits to the indigenous peoples in Hainan. However, this needs to be done carefully as it could also lead to negatives, such as exploitation of local communities.

4.4 Conclusion

Our modelling has shown that implementation of China's environmental policies could have a variety of positive consequences for giant panda conservation but also for many other species that use similar forested habitat. On Hainan Island our modelling has shown that the implementation of China's environmental policies will have positive results including increasing habitat and connectivity for endemic forest species, an increase of carbon stocks, and potential economic benefits to the islanders including indigenous peoples.

The case studies presented here drilled down to a single species and a single region; however, the methodologies we outline could be adapted to many species, if detailed range data and habitat preferences were known, or for other regions within China and beyond. This work demonstrates the utility of adapting national scale model results to the local level when considering local needs and socioeconomic circumstances.

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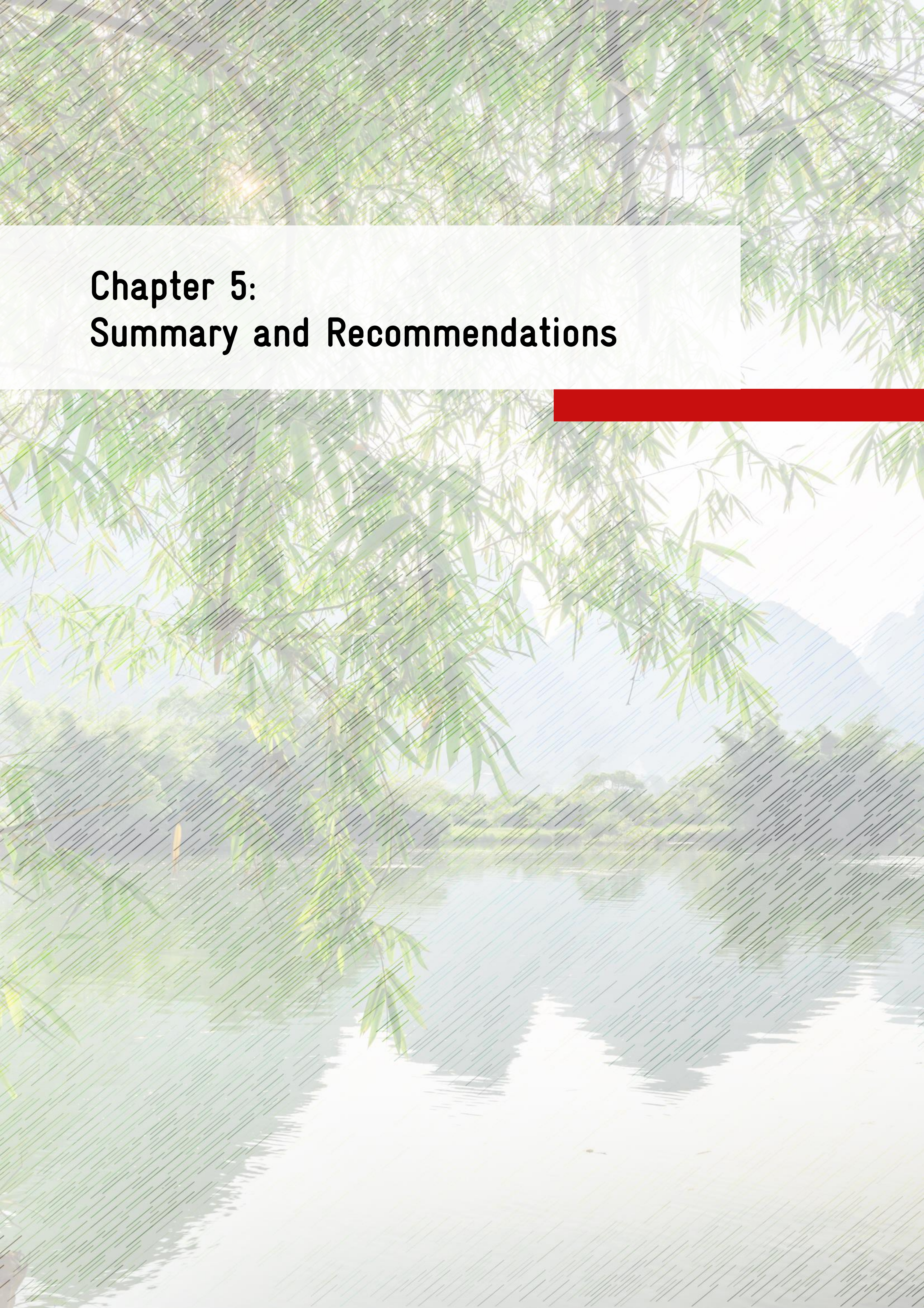
[14] http://www.qstheory.cn/dukan/qs/2022-06/01/c_1128695953.htm

[15] Explore Hainan - https://en.explorehainan.com/en/index/index.shtml

[16] http://lwt.hainan.gov.cn/rdztjs/zxlyhnlwzxd/lwzxd/202205/t20220530_3202678.html



Chapter 5:
Summary and Recommendations

5 Conclusions

5.1 What the scenarios reveal about the likely impacts of China's environmental policies

5.1.1 National results

Our scenarios explore the consequences of implementing China's environmental policies within two different socio-economic futures. The SSP2 baseline scenario (business as usual) tends to be the least favourable of the four scenarios. When conservation policies are enacted within the SSP2 policy enacted scenario many of the negative trends are reversed. However, the most positive future was consistently forecast within the policy enacted SSP1 scenario. This scenario forecasts the results of the enactment of China's conservation policies within a more sustainable society than today. The scenario estimates that biodiversity would improve through deployment of widespread restoration and conservation measures. Under this scenario agricultural intensification, while present, is not as widespread as in the SSP2 Policy scenario, because demand in production is minimised through change in diets and improved waste management, while production is increased through technological advancement in sustainable agricultural management.

5.1.2 Regional results

By focussing on specific regions, we were able to explore how the scenarios affected different regions with varying bioclimatic conditions, habitats and land uses. Biodiversity within regions B (an arid region) and C (a grassland region) within the Western Region of China tended to see greater improvements from the enactment of China's environmental policies (SSP1 Policy and SSP2 Policy) than regions A (a forested region in the northeast) and D (an agricultural region in the centre of China). These dryer regions saw faster improvements in biodiversity than region A. Region D tended to fare worse than other regions as agriculture tended to intensify here and only small areas of land were allocated for restoration or protection.

5.2 Key response options for biodiversity

Our scenarios tested the impacts of differing socio-economic drivers as well as the impact of the enactment of China's environmental policies. There are some simple response options that emerge as important from our scenario analysis which we elaborate on in the following sections.

5.2.1 Restoration of degraded forests and grasslands

The most dramatic impacts on biodiversity were linked to the restoration of forests and grasslands as detailed by China's environmental policies and captured in scenarios SSP1 Policy and SSP2 Policy. Our forecasts of the impacts of these policies under these scenarios estimated that over 400,000 km^2 of forests would be restored, and there would be a net increase of at least 70,000 km^2 of grasslands (SSP1 Policy predicted at least 120,000 km^2). The outcomes of such restoration would have widespread positive effects on biodiversity, with increases in biodiversity and ecosystem services predicted across the majority of the measures we used in the analysis.

5.2.2 Decrease of agricultural degradation of biodiversity

All four scenarios included increases in agricultural demand due to China's population growth, but demand was higher in SSP2 scenarios than SSP1 scenarios, and the intensity of production differed between scenarios, leading to dramatic differences in biodiversity outcomes.

The policy enacted scenarios forecast a future where much agricultural land was taken out of production, leading to the intensification of agriculture in the remaining lands to maintain sufficient supply. The SSP1 scenarios focussed on technological advancement leading to greater yields, and changes in behaviour and waste management resulted to lower demand in production. When comparing the biodiversity impacts of the policy response options (explored in the policy enacted scenarios) with the socio-economic response options (explored by the SSP1 baseline and policy enacted scenarios), greater short-term gain is achieved through socio-economic response options such as waste management, while more long-term gain is achieved through the conservation/restoration actions. However, the most positive future for biodiversity was forecast by SSP1 Policy. In this scenario, socio-economic drivers worked to decrease demand whereas conservation and restoration policies (as detailed in Table 3) increased the extent of natural areas throughout China, thereby combining the short and long terms gains provided by each type of response options.

5.2.3 Protected area establishment and maintenance of natural areas

Both SSP2 scenarios demonstrated the effects of agricultural optimisation. These scenarios, particularly the SSP2 baseline scenario, encoded a future where an understanding of climatic conditions drove spatial planning for agriculture, resulting in greater yields per hectare, but allowing natural areas to be removed to make way for agriculture. SSP2 Policy restrained some of the removal of natural areas, as development was not envisioned to occur within protected areas, including those areas newly designated as protected areas due to the increased protected area coverage included in this scenario, but outside of protected area boundaries removal of natural areas occurred. Whilst this approach results in an equal, or better, balance (compared to 2015) between natural and non-natural areas, it does not replace like for like. For example:

1. Many specialist species are endemic to China and removal of natural areas may result in global extinction of these species.
2. Biodiversity takes time to recover within restored areas and early successional stages will likely be dominated by widespread, generalist species.
3. Connectivity is important when considering restoration - if restored patches are located within largely converted habitat, biodiversity recovery may be further impeded, especially when considering specialist species.

5.2.4 Spatial planning including consideration of connectivity and local values

Land is valuable and finding the balance between land use priorities is complex. Our scenarios demonstrate that biodiversity is not distributed equally throughout China, both due to natural patterns of richness and uniqueness as well as current and historic pressures leading to the uneven degradation of biodiversity. Pinpointing the most important areas to conserve and restore is not as simple as selecting all areas with highest biodiversity.

In this study, we consider biodiversity significance (importance of a particular area in terms of contribution to preventing extinctions) as well as biodiversity potential (intactness of a particular area compared to a pristine circumstance). Consideration should be given to both current biodiversity significance as well as biodiversity potential when allocating areas for conservation and restoration.

Furthermore, it is important to consider connectivity of areas. Pinpointing areas to restore that have the potential to provide wildlife corridors between larger natural areas, including protected areas, will maximise the biodiversity impact of restoration.

Finally, when planning at a national level, consideration should be given to the needs of specialist species. Our case study on giant panda demonstrated the need to restore areas within giant panda habitat to maximise both area and connectivity of habitat.

Spatial planning efforts are most effective at a national level to ensure national priorities are addressed and needs for biodiversity and human well-being are met. However, national planning is most effective when connected with local planning processes, driven by an understanding of local values and needs.

Scenario outcomes at a national scale hide differing trends when viewed at a regional scale. For instance, when considering the futures described in the policy scenarios, the grasslands in the Western Region tended to gain higher levels of biodiversity than those in the central agricultural regions. Local needs and values must be considered to understand whether this trade-off is significant.

5.3 Limitations of our results and recommended further work

5.3.1 Methodological limitations

While we can make broad conclusions about the influence of different response options, it is not possible to quantify the influence of each without running individual scenarios for each response option. This approach was not taken in this study, as, although it could provide refined estimates for individual actions, it would not account for the many interactions, synergies and trade-offs between the differing response options, and therefore would not provide realistic options for China's biodiversity outlook. Rather the scenarios we explore should be taken to represent plausible futures where different elements of development are prioritised. For instance, in our policy enacted scenarios, conservation actions such as restoration and conservation are prioritised. In the SSP1 baseline scenario, indirect drivers such as sustainable technological development, waste management and environmental education are prioritised.

The scenarios we developed focus on terrestrial ecosystems, but further work could expand these scenarios to include marine or freshwater ecosystems. Such work would allow the investigation of important interactions, such as the interaction between terrestrial land use change and freshwater ecosystem health or the investigation between the trade-offs of feeding a population using terrestrial vs marine protein sources.

5.3.2 Policy limitations

Our results focus on current conservation-relevant policies that were able to be quantified and made spatially explicit. However, other policies will be highly influential on the outcomes of our scenarios. For instance, China's 14th Five-Year Plan (2021-2025) includes various chapters focussing on development, with one emphasizing on regional development, particularly for its interior regions. The Plan also highlights the need to strengthen modern agricultural practices to improve the efficiency and competitiveness of agriculture. A knowledge of the possible influences of other policies will not only allow an examination of potential synergies but will also provide information on the feasibility of the scenarios and responses described by this work. Further work would target these policies to try to examine when synergies can be found to achieve multiple goals such as those outlined by the Sustainable Development Goals (SDGs)[17].

5.3.3 The changing political landscape

Our results provide a significant insight into the biodiversity consequences of the implementation of China's current conservation policies, such as forest and grassland restoration and protected area expansion. However, the policy climate is constantly changing, and the international community is currently focussed on the development of new goals and associated targets in the post-2020 global biodiversity framework (GBF), being negotiated under the auspices of the CBD. It is anticipated that

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[17] Sustainable Development Goals - https://sdgs.un.org/goals

China will update conservation policies to be in alignment with the GBF. Our framework could usefully be adapted to encompass these new or revised biodiversity-related goals and targets.

5.3.4 Multi-scale and multi-criteria planning

Our models provide a cutting-edge representation of current day biodiversity and possible trends into the future. However, the patterns and responses we describe are, by necessity, based on average responses or general assumptions (for example, our species ranges are based on broad habitat categories), and relate to the examination of futures defined by national level policy responses. Future work should drill down into the regional and local differences. Local, stakeholder driven scenarios provide insight into local priorities and values, and local land use inputs provide greater insight into pressures on and opportunities for biodiversity.

Prioritisation of areas for conservation should likewise follow a multi-criteria approach, based on a range of goals (such as the SDGs, or the Nature Futures Framework) as well as local needs. Such approaches are complex and time-consuming, but the results presented here provide some important first steps towards these more refined analyses including the development of land, biodiversity and ecosystem service models specific to China, and the linkage of these models to national level policies. Our methodology can be adapted to incorporate local and regional priorities, as well as the incorporation of further policy goals. For instance, our work highlighted the Western Region as an area with the potential to undergo extensive biodiversity restoration. However, this region contains one of China's most important food security zones as well as two of China's seven Key Ecosystem Protection and Restoration Progammes. Further work would be needed to ascertain if the solutions predicted within our scenarios achieve the balance between ensuring food security yet protecting the Yangtze River against harmful agricultural run-offs.

5.3.5 Taking the methodology further

Our work clearly demonstrates the potential biodiversity impacts of China's environmental policies. But beyond the knowledge gained by the analysis of the scenarios there are two further outputs from this work.

The first is the current day assessment of China's biodiversity. Although this was not a focus for this work, we believe that the land use, habitat and biodiversity information gathered to quantify the 2015 reference point could be useful for policy makers interested in assessing the recent and current status of biodiversity. The data layers developed in this work could be refined with local data to further the usefulness of these layers for policy makers.

The second output is the modelling framework itself. As mentioned above, the post-2020 global biodiversity framework (GBF) is currently being negotiated including the text around a new set of goals and targets. Our modelling framework could be adapted to test the consequences of implementing the GBF, both by China as well as by other interested countries. Methodological frameworks such as the one we present provide vital information on whether the world will, through the goals and targets outlined by the GBF, achieve its critically important ambitions for nature and people.

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Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

Sitz der Gesellschaft
Bonn und Eschborn

Friedrich-Ebert-Allee 32 + 36
53113 Bonn, Deutschland
T +49 228 44 60-0
F +49 228 44 60-17 66

Dag-Hammarskjöld-Weg 1-5
65760 Eschborn, Deutschland
T +49 61 96 79-0
F +49 61 96 79-11 15

E info@giz.de
I www.giz.de