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Nature Loss and Sovereign Credit Ratings

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Comments and queries about this report, our broader debt workstream, and other Finance for Biodiversity workstreams, should be addressed to contact@f4b-initiative.net.

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The views expressed in this paper are those of the authors alone. Any errors are our own.

About FINANCE FOR BIODIVERSITY Initiative

F4B's goal is to increase the materiality of biodiversity in financial decision-making, and so better align global finance with environmental conservation and restoration.

Our work on Sovereign Debt draws from the entirety of our portfolio, which is organised across five workstreams:

- **Market efficiency and innovation:** including a leadership role in the Taskforce on Nature-related Financial Disclosures (TNFD), and support to several data- and fintech-linked initiatives.
- **Enhanced liability:** extending the legal liabilities of financial institutions for biodiversity outcomes, including innovations such as legal personhood for nature.
- **Citizen engagement:** public advocacy, campaigning and advancing digital approaches to catalysing shifts in citizens' financing behaviour.
- **Public finance:** advancing measures and advocacy linked to stimulus and recovery spending, and the place of nature in sovereign debt markets.
- **Nature markets:** catalysing nature markets by developing new revenue streams and robust governance innovations.

F4B has been established with support from the MAVA Foundation, which has a mission to conserve biodiversity for the benefit of people and nature. F4B's work benefits from partnership with, and support from, the Children's Investment Fund Foundation (CIFF) and the Gordon and Betty Moore Foundation through The Finance Hub.

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The SOAS Centre for Sustainable Finance aims to advance the transition to an equitable, low-carbon economy by providing a forum for interdisciplinary research and teaching on sustainable finance and investment. It seeks to enhance the knowledge and understanding of sustainable finance in both the Global North and South and act as a focal point for policy debates in this area. Located at SOAS, University of London, in the heart of one of the world's leading financial hubs, the Centre's research and policy work addresses pressing issues including green financial governance; the impact of climate and environmental risks on public and corporate finances; the scaling up of low-carbon and resilient investment in vulnerable countries; climate risk insurance; mobilising financing for the Sustainable Development Goals; inclusive green finance; low-carbon innovation policy and renewable energy investments; and the role of public financial institutions in advancing the green transition.

The Centre is part of the Global Research Alliance for Sustainable Finance and Investment, a network of leading research universities, as well as the International Network for Sustainable Financial Policy Insights, Research, and Exchange, a global research network that feeds into the work of the Network of Central Banks and Financial Supervisors for Greening the Financial System. It is also a knowledge partner of the Green Growth Knowledge Partnership and the Asia Sustainable Finance Initiative, and host to the Sustainable Finance Data Initiative, an innovative new venture gathering data on inflows and outflows of climate and sustainable finance in developing and transition economies.

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For more information, visit https://www.soas.ac.uk/centre-for-sustainable-finance/

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Launched in 2018, the Bennett Institute is committed to interdisciplinary academic and policy research into the major challenges facing the world, and to high-quality teaching of the knowledge and skills required in public service.

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The Bennett Institute for Public Policy at the University of Cambridge aims to develop successful and sustainable solutions to some of the most pressing problems of our time. This is a critical moment for this aim, which has at its heart a commitment to a deeper analysis of the economic, social and political systems in which policy is developed; the creation of powerful new networks of policy-makers, influencers and researchers; and the development of a new generation of reflexive and critical policy leaders. We bring together the world-class research of Cambridge in technology, engineering and the natural sciences with a deep understanding of the social and political forces that are remaking democracy and generating fundamental challenges for governments across the world.

Our work reflects a readiness to move away from the technocratic assumption that there are technical fixes or ready-made solutions to intractable challenges arising from resource scarcity.

All of our research is directed towards improving understanding of public policy challenges, and none of it is in any way politically motivated or directed. It is funded by a variety of sources including competitively won awards from research councils, trusts, and foundations, and also by philanthropic donors. The Institute is driving forward research into the growing demand for a more equitable distribution of the world's natural and social assets and examine the impact that technological change is having on the nature of work, community and consumption around the world.

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Contents

EXECUTIVE SUMMARY 7

1 SETTING THE SCENE: WHY BIODIVERSITY AND NATURE-RELATED RISKS MATTER FOR SOVEREIGN DEBT 11

2 INCORPORATING BIODIVERSITY AND NATURE-RELATED RISKS INTO SOVEREIGN DEBT 13

3 ESTIMATING THE MACROECONOMIC CONSEQUENCES OF NATURE LOSS: THE WORLD BANK'S 'MAKING THE ECONOMIC CASE FOR NATURE' REPORT 16

4 METHODOLOGY 19

5 DISCUSSION OF EMPIRICAL RESULTS 23

6 CONCLUSION AND POLICY RECOMMENDATIONS 38

REFERENCES 40

ENDNOTES 42

APPENDIX 43

Executive Summary

Biodiversity loss, decline of ecosystem services, and overall environmental degradation can hit economies through multiple channels. The combined macroeconomic consequences can impact sovereign creditworthiness. Yet, the methodologies published and applied by leading credit rating agencies (CRAs) do not explicitly incorporate biodiversity and nature-related risks. Omitting them may ultimately undermine market stability. As environmental pressures intensify, the gap between the information conveyed by ratings and real-world risk exposure may grow. A consistent approach to integrating nature- and biodiversity-related risks into debt markets is long overdue.

This report models the effect of nature loss on credit ratings, default probabilities, and the cost of borrowing. The results have implications for stakeholders including credit rating agencies, investors, and sovereigns themselves.

1 IMPLICATIONS FOR CREDIT RATINGS AGENCIES

Biodiversity- and nature-related risks can have significant impacts on sovereign creditworthiness, default probability, and the cost of capital. Environmental macroeconomic models are increasingly able to describe direct economic consequences of nature and ecosystem service loss.

Credit rating agencies can and should incorporate nature-related risks into rating methodologies. As environmental pressures mount and the potential economic consequences become more severe, the gap between the risks incorporated in ratings and those faced in the real world will grow.

2 IMPLICATIONS FOR INVESTORS

Ratings that ignore biodiversity loss are omitting a significant source of risk. Investors who rely on nature-blind measures of creditworthiness will be unable to correctly identify, price, and manage risk across their portfolio.

Backward-looking risk assessments are insufficient. Whilst it is important to acknowledge that nature loss and climate change have already begun to impact the cost of borrowing for some sovereigns, investors should apply forward-looking risk metrics that address forthcoming risks based on the best possible science.

3 IMPLICATIONS FOR GOVERNMENTS

Economies with high dependence on ecosystem services face a choice: pay now, by investing in nature, or pay later through reduced fiscal space and higher borrowing costs. The 'pay now' option generates long-term returns for people, business, and nature. The 'pay later' option entails significant downside risks, with little to no upside.

This is not just a story for financiers and finance ministries. It is not only the financiers that lose out when ecological damages affect the creditworthiness of nations but also ordinary people who need to make payments on their mortgages every month that will be affected once interest rates go up.

There is a strong economic rationale to sovereigns themselves to take action to reverse the trend in nature decline. Economies that maintain or enhance natural capital could in principle see their creditworthiness improved, as depletions elsewhere make their natural assets scarcer and more valuable.

Conceptually, incorporating biodiversity- and nature-related risks into sovereign ratings is no different from including other difficult to quantify risks – such as geopolitical risk or contingent liabilities – that are already embedded in ratings methods. A common excuse for excluding biodiversity- and nature-related risks is that the scientific uncertainty is allegedly too high. But this argument is increasingly inaccurate. Science has been progressing continuously, enabling the integration of nature into the analysis of sovereign credit risk.

The omission of nature risks in sovereign assessments is no small matter. According to World Bank estimates, the cost of national GDP loss following a partial collapse of ecosystem services would exceed the GDP loss caused in 2020 by the Covid-19 pandemic in around half the countries for which data is available. While a pandemic is impossible to predict for rating agencies, the risk of biodiversity loss can be more precisely quantified and geographically localised. Given the potential size of the related economic risk for individual sovereigns, the inclusion of nature risks into sovereign risk frameworks is not only expedient, but inevitable.

Using the most advanced AI methodology, this report models the effect of nature loss on credit ratings, default probabilities, and the cost of borrowing for 26 sovereigns. We estimate these effects under multiple scenarios describing the trajectory of nature decline: a 'status quo' scenario, in which nature-loss is halted and there is no further decline; a 'business-as-usual' scenario in which current trends of nature-loss continue into the future; and a 'partial nature collapse' scenario, in which continued degradation leads to ecological tipping points (i.e. ecosystems collapse). Building on cutting-edge World Bank research, we focus on the effects of changes in fisheries, tropical timber, and wild pollination services up to the year 2030.

The 'partial nature collapse' scenario is the most severe. It is based on the established scientific understanding that biodiversity endowment, and the ecological services that come with it, are subject to tipping points, which can be hard to predict in practice. Accordingly, the negative economic and ratings consequences tend to be the most severe under this scenario.

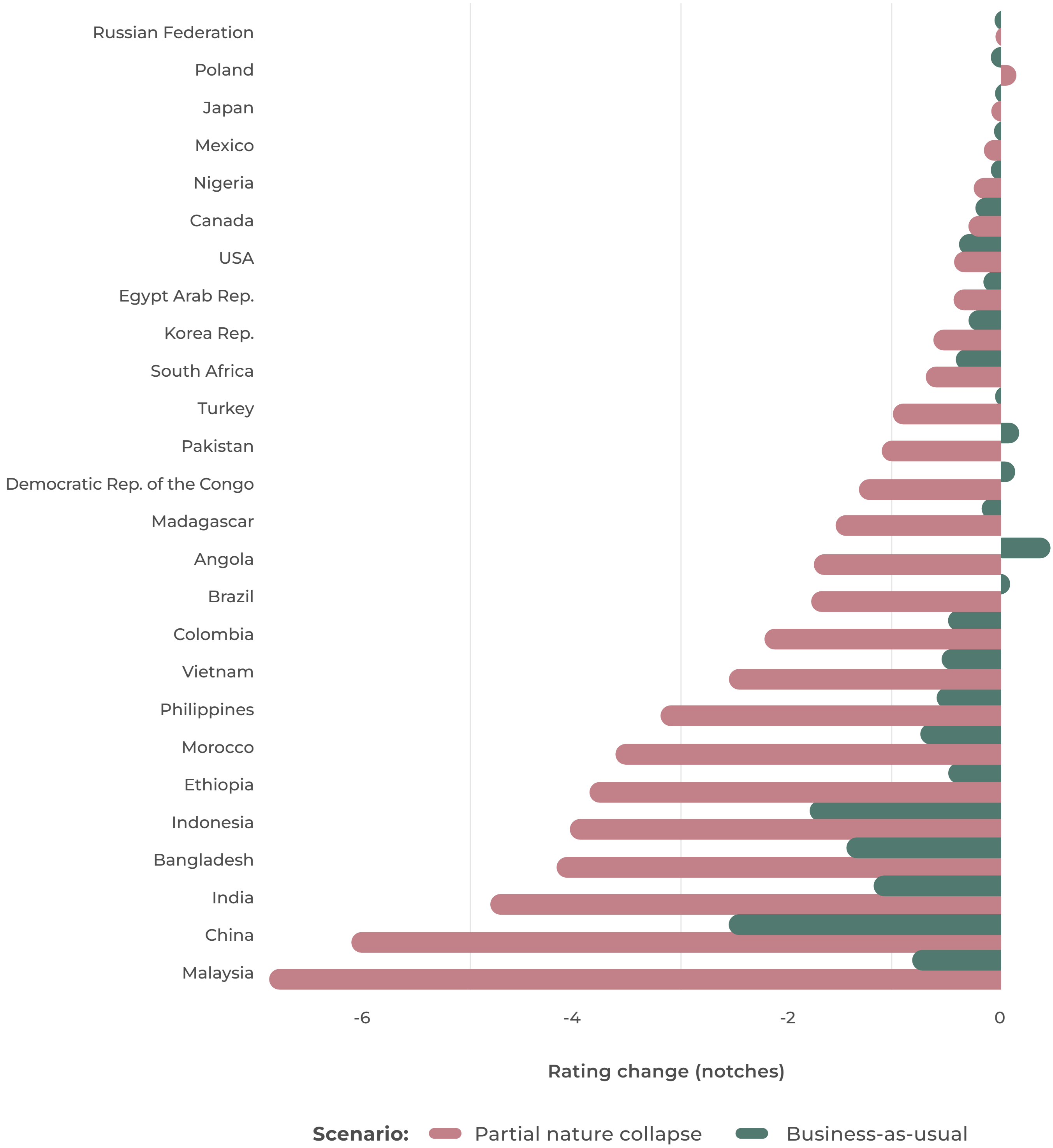
The ratings impact under the partial ecosystem services collapse scenario is in many cases significant and substantial (see Figure ES1). More than half (58%) of the sovereigns included in the sample would face a downgrade of one notch or more. Those downgrades would in turn trigger between $28-53 billion in additional costs of annual interest payments borne by these downgraded governments.

At the same time we see a wide variety of outcomes across the sample. About a third of the sovereigns (31% of the sample) would see their rating lowered by more than three notches. A partial collapse of ecosystem services would most directly impact the creditworthiness of lower-rated sovereigns in emerging and developing countries. For highly rated sovereigns, the estimated rating changes are generally small and within the margins of error.

China and Malaysia would be hit the hardest, with rating downgrades by more than six notches in the partial collapse scenario. India, Bangladesh and Indonesia would face downgrades of approximately four notches. For China, the drop in creditworthiness would amount to additional interest on sovereign financing of between $12-18 billion, while the country's highly indebted corporate sector would incur an additional $20-30 billion cost on its debt. With a nearly seven notches sovereign downgrade, Malaysia would see an increase of its cost of sovereign debt between $1-2.6 billion, while corporates in Malaysia would need to cover additional $1-2.3 billion in interest expenses. More importantly, these two sovereigns would cross from investment- to speculative-grade, with potential regulatory implications for institutional investors.

Figure ES1 also shows the estimated downgrades under the business-as-usual scenario. Business-as-usual would result in a downgrade of one notch or more for only four of the 26 sovereigns (15%) by the year 2030. China and Indonesia are the two countries that would face the largest downgrades under the business-as-usual scenario, each with downgrades of approximately two notches.

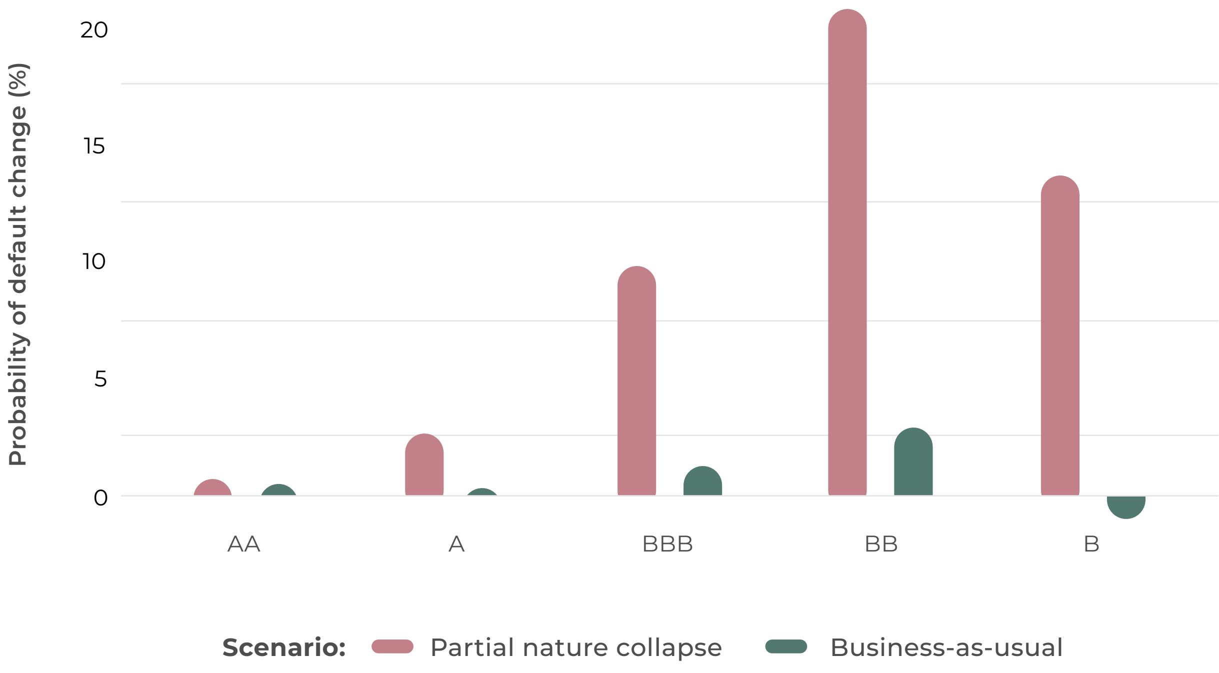
Figure 1 ES | Rating changes due to partial nature collapse and BAU (gradual nature loss at current rates)



The rating scale applied by rating agencies expresses an analytical opinion on the relative default probability (PD). But the relationship between ratings and PD is not linear. Instead, the historically observed likelihood of default increases progressively as we move down the rating scale. While the PD changes only incrementally when moving from one high rating to the next lower one, the increase in PD is much higher when downgrading from an already low rating.

We therefore also calculate separately the effect of nature loss on PD. Figure ES2 shows that these would be unevenly distributed across the ratings scale. Under the partial collapse scenario, 12 countries (Bangladesh, Ethiopia, India, Malaysia, Madagascar, Angola, Indonesia, Morocco, Democratic Republic of Congo (DRC), Vietnam, Pakistan and Brazil) or 46% of our sample would face an increase in the PD of more than 10%. The PD would increase under a partial ecosystem collapse the most for Bangladesh (41%), Ethiopia (38%) and India (29%). Adding nature risks to an often already high PD would pose significant solvency concerns.
In the partial ecosystem collapse scenario, six countries (Madagascar, DRC, Bangladesh, Angola, Ethiopia, and Pakistan) would face an absolute PD of over 50%. In other words, a default would be more likely than not should these countries be hit by a sudden collapse of nature.

Figure 2 ES | Average probability of default change by rating category (in % points, classified by 2020 estimated rating)



1

Setting the scene:
why biodiversity- and nature-related risks matter for sovereign debt

Despite a proliferation of new instruments to help sovereigns and investors better integrate nature into debt markets, several key gaps still remain which prevent the full integration of nature-related risks and opportunities into debt markets at large. This report is a first-of-a-kind analysis on the role of the broader market infrastructure in embedding nature in sovereign debt markets, specifically the role of credit ratings. In particular, it seeks to shed light on how nature fits into credit ratings models and the impact of incorporating these risks and opportunities in ratings.

Mounting evidence shows that environmental-economic risks extend well beyond the climate system to include biodiversity loss and broader environmental change (Pinzón et al. 2020, NGFS-INSPIRE Study Group 2021). Whilst climate and the environment continue to dominate the World Economic Forum's Global Risks Report 2021 and annual risk perceptions survey, biodiversity loss ranked in the top five risks by likelihood and impact for the first time in 2020 (and remained in 2021) (World Economic Forum 2021). Research shows that deforestation and species loss make pandemics such as Covid-19 more likely (Tollefson 2020), with immediate and significant human and economic costs. Additionally, a recent World Bank report estimates that the reduced pollination, fisheries, timber production, and related ecosystem services could result in a decline in global GDP of $2.7 trillion annually by 2030 (Johnson et al. 2021).

Markets and investors are trying to incorporate these risks into decision making. Firms, industry groups, NGOs, and international institutions are developing toolkits, sustainability strategies, and environmental, social and governance (ESG) criteria to monitor and help mitigate nature-negative impacts. The newly formed Taskforce on Nature-related Financial Disclosures (TNFD) seeks to create a framework for organisations to report and act on evolving nature-related risks, to support a shift in global financial flows away from nature-negative outcomes and toward nature-positive outcomes. In 2021, world leaders met (virtually) in Kunming, China for COP15 of the UN Convention on Biological Diversity and in Glasgow, Scotland for COP26 on climate change to set national and international targets, that will only increase the impetus for markets to take action.

Sovereign debt – the world's largest asset class[1] – is not immune to these trends and risks, and investors are beginning to take note. Financial institutions with more than $7 trillion under management wrote to the Brazilian government demanding a reduction in deforestation to prevent widespread divestment (Financial Times 2020, 2021; Reuters 2020). At the same time, retailers have threatened boycotts of Brazilian products and EU Member States have delayed trade deals over similar concerns. These events demonstrate investors' willingness to act when it comes to nature and sovereign debt, but they are as yet isolated and ad hoc examples. A consistent approach to integrating nature- and biodiversity-related risks into debt markets is long overdue.

Sovereign debt markets also present opportunities for financial innovation, spurring a green recovery that builds forward toward a more sustainable and resilient future (Agarwala et al. 2020). The economic response to the Covid-19 pandemic saw public debt to GDP ratios soar. But this has not reduced the investment needs to safeguard biodiversity and meet environmental targets and commitments set out in domestic and international law. Simultaneously, public opinion is shifting such that investors and financial institutions are increasingly determined to 'green' their portfolios. With little fiscal space remaining, governments must crowd-in private finance to stimulate growth- and resilience-enhancing investments. Whilst many green bonds have focused largely on climate, there is growing interest in incorporating biodiversity and creating sustainability- and nature-linked bonds (Volz 2022). Whilst biodiversity bonds have the potential to bring substantial financial backing to help reverse the decline, a key challenge remains: How do we evaluate both their risks and environmental benefits?

In this report, we conduct the first ever analysis of nature-related risks for sovereign credit ratings. The report is structured as follows. Section 2 highlights the importance of incorporating biodiversity- and nature-related risks into sovereign ratings. Section 3 discusses the relevance of the quantitative analysis of the macroeconomic consequences of nature loss presented in the World Bank's recent report on Making the Economic Case for Nature, the results of which we use for our own modelling of the impact of nature loss on sovereign credit ratings. Section 4 will set out the methodology developed for our analysis, and Section 5 will present and discuss our empirical results. Section 6 will conclude the report with a set of policy recommendations.

2

Incorporating biodiversity- and nature-related risks into sovereign ratings

Sovereign risk assessments that omit biodiversity- and nature-related risks are incomplete, leading to mis-priced risk, and reducing the relevance and reliability of sovereign credit ratings. Biodiversity loss and environmental degradation can hit economies through multiple channels. In many instances, such as fisheries collapse, economic losses are concentrated within a single sector, with ripple effects along the supply chain and affiliated industries (processing and transport). As the Covid-19 pandemic has demonstrated, however, biodiversity-related risks can also generate systemic and global economic losses. The loss of ecosystem services on which large parts of the economy rely could cause output losses and rising unemployment, with adverse effects on public finances. Moreover, as floods, droughts, and fires increase in frequency and intensity, in large part due to deforestation and ecosystem destruction, material risks to sovereign debt could rise. Credit ratings that fail to reflect these risks may not only lose relevance but may ultimately undermine market stability as they are heavily relied upon by regulators and investors.

BOX 1
The role of sovereign ratings in sovereign debt markets

Investors and market actors interested in 'greening the financial system' face a fundamental challenge: Despite growing evidence of the economic consequences of biodiversity loss, there is still no agreed strategy for translating environmental degradation into material risks for investors.

Credit ratings agencies (CRAs) work to identify, assess, and quantify risks, offering investors an 'inside-look' into the creditworthiness of sovereign issuers. They help translate relevant information into material risk assessments, and the ratings they assign affect both the cost and allocation of debt finance around the world.

Although sovereign ratings assess the creditworthiness of governments, their influence also impacts private debt markets. The well-known 'ceiling' and 'spill over' effects describe how sovereign ratings effectively impose a cap on ratings in other asset classes, and how sovereign downgrades often trigger corporate and financial institution downgrades (Almeida et al. 2017). Such ratings are part of the DNA of global debt markets, affecting banks' capital requirements and determining which bonds institutional investors (pension funds) can hold.

Along a similar line of argument, those countries effectively protecting or even enhancing their biological assets could in principle see their creditworthiness improve, because the loss elsewhere makes their conserved natural assets globally scarcer and thus potentially more valuable. At the same time, the conservation of natural assets and the promoted resilience may require significant public outlays, which could in turn lead to downward pressure on the rating as sovereign debt rises in the interim above levels that would have otherwise been observed. As the agencies' ratings horizon is typically not extending beyond a few years (Kraemer 2021), foregoing the short-term benefit of export revenues from cash crops might also lead to lower ratings, even if the economic value of the biodiversity sacrificed in the process may in the longer term far exceed the short-term export benefits.

Ratings agencies recognise the need to incorporate nature-related risks in their assessments. So far, these efforts have largely emphasised climate change (S&P Global 2015) rather than biodiversity, operate mostly in the context of ESG ratings, and have resulted in the creation of satellite indicators rather than changes in core ratings calculations and methodologies. More recently, ratings agencies have begun to consider biodiversity risks specifically (Fitch 2021, Vanstone et al. 2021). Moody's, for example, has joined the Taskforce on Nature-related Financial Disclosures (TNFD) in a quest to enhance its credit analysis to better reflect biodiversity. The agency's ambition appears to be centred around corporates only, however, omitting sovereign ratings and impacts on whole economies (Moody's 2021). Key challenges relate to the fact that environmental reporting definitions and methodologies are not standardised, especially along complex global supply chains (S&P Global 2021). Whilst there is activity on behalf of ratings agencies, there remains considerable work to be done before nature is fully integrated into sovereign ratings, and the associated risks and opportunities are adequately priced in.

Existing ratings methodologies do not explicitly incorporate nature-related risks. The methodologies published and applied by leading CRAs largely focus on governance, economic, external, monetary, and fiscal factors, but do not explicitly incorporate biodiversity and nature-related risks. It is, however, possible that environmental factors could indirectly affect ratings through their impact on the factors already included in the ratings model. For instance, there is strong evidence that climate change has already raised the average cost of debt in vulnerable developing countries (Kling et al. 2018; Buhr et al. 2018; Volz et al. 2020; Beirne et al. 2021a, 2021b).

Conceptually, incorporating biodiversity- and nature-related risks into sovereign ratings is no different from incorporating geopolitical or other highly uncertain risks. All sovereign methodologies include efforts to quantify potential liabilities that are hard to anticipate in either scope or timing. For example, contingent liabilities related to bailing out a failing financial sector or strategic or state-owned enterprises are part of the standard repertoire of sovereign risk factors. Similarly, assessing the vulnerability to geopolitical risk is a common feature of established sovereign methodologies. In some cases, a negative adjustment is made to a sovereign's rating for outsized exposure to geopolitical risks, even if those risks have not materialised for many years or decades. CRAs use specific proxies, or simply judgement, to incorporate those risks into the final ratings profile of a sovereign.

A common excuse for excluding biodiversity- and nature-related risks from financial risk assessments is that the scientific uncertainty is allegedly too high. In fact, that uncertainty is not fundamentally different from the uncertainties surrounding issues of geopolitical risks or contingent liabilities. What is different, however, is that the financial services industry has only recently begun to acknowledge the fact that nature-related risks will have material impacts. Methodologies have not yet caught up with this new trend. But that is no valid reason to close our eyes to those emerging risks. In fact, one leading rating agency has recently acquired a company specialising in assessing cyber risk, another superficially amorphous risk. This research is aimed at helping CRAs to take similar steps into the hitherto underappreciated field of nature risk.

The omission of nature risks in sovereign assessments is no small matter. Some estimates suggest that almost half of the world's GDP is 'moderately or highly dependent' on nature and its services to humanity (World Economic Forum 2020, Retsa et al. 2020). That share can be significantly higher for individual countries. Some developing countries are particularly dependent on natural capital.

According to World Bank estimates (Johnson et al. 2021), the cost of national GDP loss following a hypothetical collapse of the services hitherto provided for free by nature would exceed the GDP loss caused in 2020 by the Covid-19 pandemic in around half the countries for which data is available. In other words, a collapse of biodiversity would in many instances have a more severe economic impact than what has been arguably the biggest global economic shock in living memory.
The pandemic has also been the biggest single trigger for an unprecedented wave of sovereign downgrades during 2020 (Tran et al. 2021).

A pandemic is impossible to predict for rating agencies, both in epidemiological and geographical scope. It would therefore be unreasonable to expect a quantification of pandemic risk in sovereign risk methodologies to be applied to individual issuers. The risk of biodiversity loss, on the other hand, can be more precisely quantified and geographically localised (WWF et al. 2022).
The root causes of biodiversity loss are well understood by ecologists, and progress in satellite surveillance has made it easier to track developments such as land use change at ever finer spatial resolution. Given constantly improving information and the potential size of the related economic risk for individual sovereigns, overshadowing anything so far observed in peace times, the inclusion of nature risks into sovereign risk frameworks is not only expedient, but inevitable.

3

Estimating the macroeconomic consequences of nature loss:

the World Bank's 'Making the Economic Case for Nature' report

There is growing recognition that biodiversity- and nature-related risks could have significant consequences for the global financial system. Ecological data confirms that many forms of natural capital and the associated ecosystem services are in decline. Whilst many of the resulting economic consequences may be acute and isolated (e.g. the collapse of a local fishery), the high dependence of some sectors and economies on nature (NCFA 2020), alongside the systemic nature of ecological collapse, point to the possibility that nature loss could have significant macroeconomic implications.

The 2021 World Bank report Making the Economic Case for Nature (Johnson et al. 2021) presents a first-of-its-kind attempt to identify the macroeconomic consequences of nature loss. Focussing on a collapse in the provision of select services including wild pollination, provision of food from marine fisheries and timber, the report shows that nature loss could result in a significant decline in global GDP – an estimated $2.7 trillion in 2030.

The report combines a globally integrated modelling exercise with scenario analyses to consider the macroeconomic consequences of nature loss between 2022 and 2030. The time frame is for illustrative purposes only and mirrors the time frame adopted by the World Bank in the study (Johnson et al. 2021). As a collapse of nature is a sudden and hard to predict event it could happen before 2030, after 2030, or, indeed, never. A global general equilibrium model is linked to a suite of science-driven environmental economic models of ecosystem service provision, covering pollination, timber provision, fisheries, and carbon sequestration.

The framework paints a landscape of possible scenarios of the interaction between these ecosystem services and the economy to 2030. The key driver of change in the model is land use change – both an outcome of economic activity and a key determinant of ecosystem service provision. Crucially, land use change is endogenously determined in the model, meaning it captures feedback loops and responds to changes in the economy.

At the core of the analysis is a computable general equilibrium (CGE) model. CGE models are a class of economic models used to estimate how an economy may react to changes in policy, technology, or other external factors. They represent the economy through a series of equations that mimic the existence of multiple decision makers (for example, firms, households, and governments) that interact in multiple markets for intermediate and final goods and services.

As demand and supply adapt in the different markets, so do the prices and quantities traded, resulting in an equilibrium level of global output, welfare, and use of resources. The reason it is important to combine the ecosystem service models with the CGE is that it allows the mapping of a multitude of independently small environmental changes onto related sectors and broader macroeconomic trends.

When the CGE model is linked to the suite of ecosystem service models, a range of scenarios can be explored. First, a business-as-usual scenario (where nature loss continues at current rates) is projected to 2030 using a standard set of assumptions about demographic and economic growth.

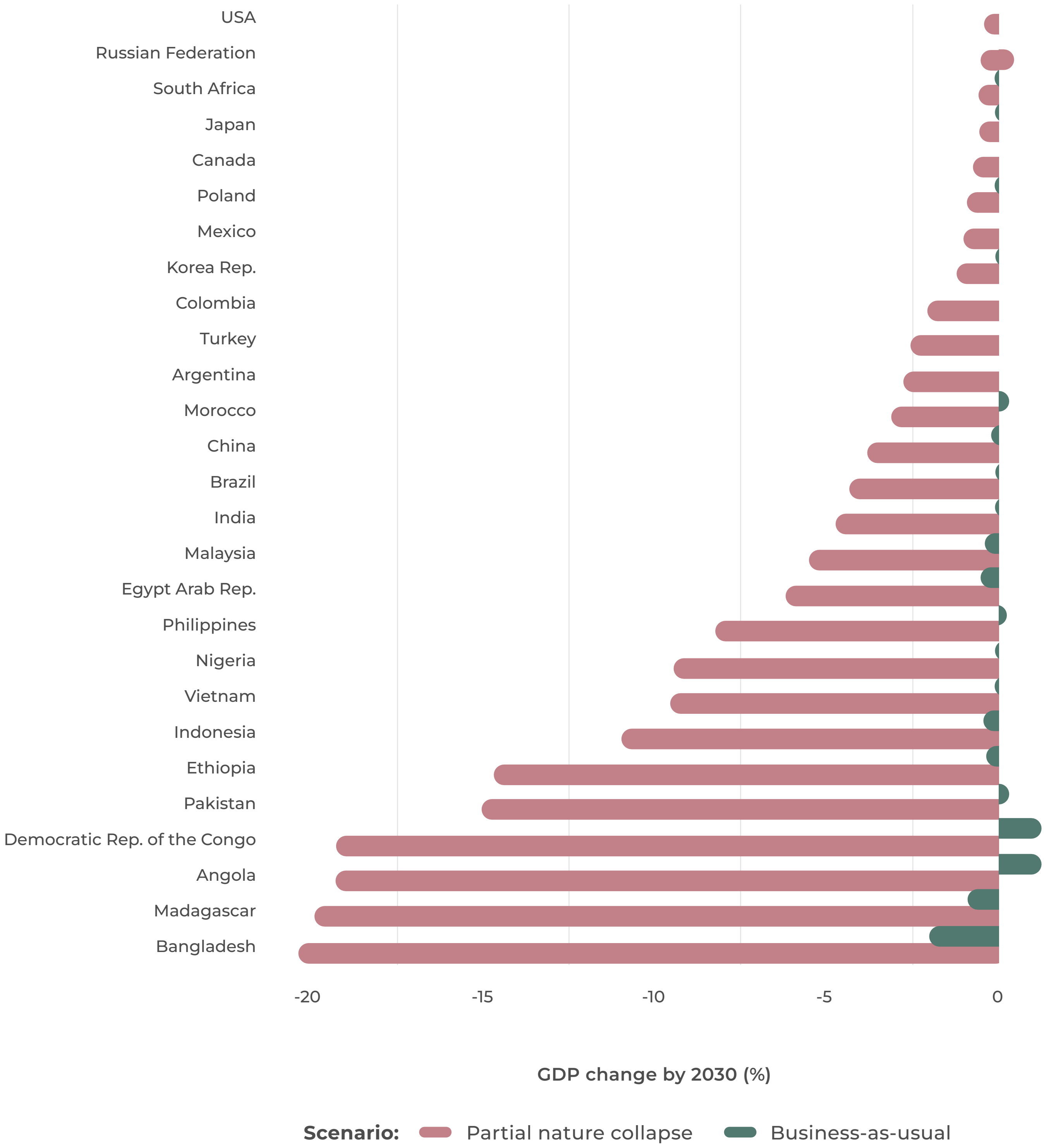
Next, a range of potential scenarios are considered, including one in which there is no further loss of nature (a status quo, but not business- as-usual), and another in which key ecological tipping points are reached, resulting in partial ecosystem collapse. Finally, a range of policies are considered which would interact with various components of the model, including changes in nature loss (ecosystem service provision) and in economic policies (e.g. taxes and subsidies). The scenarios are described in Johnson et al. (2021), with key features reproduced in Table 1.

Table 1 | Biodiversity scenarios explored in this analysis

	Baseline (AKA status quo, or no further nature loss)	**Business-as-usual (AKA maintain current trajectory)**	**Tipping points (AKA partial ecosystem collapse)**
Brief description	Projects global economy in 2030 using standard assumptions about economic and demographic growth, excluding feedbacks on ecosystem services	Nature continues to decline at its current rate out to 2030. Nature loss reduces ecosystem service provision, with knock-on effects for the rest of the economy	Nature suffers a partial collapse. Key ecosystems face tipping points. Domino effects of ecosystem service loss on the rest of the economy are incorporated
Key biophysical effect	Although growth increases environmental pressures, this relationship is not featured in the baseline scenario	Conversion of 46 million hectares of natural land between 2021-2030 to managed forests (+17m ha), pastureland (+15m ha), and cropland (+13m ha)	Loss in agricultural productivity due to pollinator loss, loss in marine fisheries productivity due to reduced biomass, widespread conversion of tropical forest to savannah
Ecosystem projections	N/A	• 0.3% reduction in global forestry production • 2.8% reduction in global marine fisheries production • 791m metric tons of CO2 (Additional) • 2.8% increase in pollinator-dependent agricultural productivity (due to expansion of agricultural land)	90% reduction in the flow of ecosystem services value of: • wild pollination • marine fisheries • timber provision
Economic projections	• Average annual per capita global GDP growth of 2.8% • Population in 2030 is predicted to be 8.3 billion	• Global loss of GDP of $90 - $225 billion	• Global GDP in 2030 shrinks by $2.7 trillion (-2.3%) compared to baseline • Equivalent to a 10% decline in 2021 – 2030 global GDP growth
Further information		Johnson et al. (2021) Figure 1	Johnson et al. (2021) Figure 1

Figure 1 displays the losses in 2030 GDP under the World Bank's partial ecosystem collapse (or tipping point) scenario and the business-as-usual scenario, compared with the no-further-loss-of-nature scenario. We will use this partial ecosystem collapse scenario as well as the business-as-usual scenario in the following to illustrate our approach, and the results we obtain in terms of sovereign credit rating changes and impacts on the cost of capital.

Figure 1 Change in 2030 GDP under the partial ecosystem collapse scenario and a gradual nature loss at current rates under the business-as-usual scenario compared with the no-nature loss scenario (% of GDP)



Source: Compiled with data from Johnson et al. (2021).

In summary, the World Bank's Making the Economic Case for Nature report represents the most sophisticated, scientifically and economically rigorous attempt to date to assess the macroeconomic effects of nature loss. As such, we use its results to inform our approach to assessing the effects of nature loss on sovereign debt, credit ratings, and default probabilities.

4

Methodology

In this section we outline the methodology for estimating the impact of the loss of nature and biodiversity on sovereign credit ratings. The model developed for this purpose builds on that of Klusak et al. (2021). We first provide an overview of the model building process and our statistical techniques. We subsequently discuss how we adjust our data for GDP losses associated with biodiversity and nature loss, and produce biodiversity/nature-adjusted sovereign credit ratings.

Our model makes use of a machine learning technique referred to as random forest classification. Our modelling approach is split into two steps. In step 1, we collect macroeconomic data for a range of countries and their associated credit ratings. We process this using a random forest model, which then enables us to make predictions about credit ratings with new data. In step 2, we adjust our macroeconomic data for changes in GDP, as estimated by Johnson et al. (2021), and then use our model developed in step 1 to predict the ratings change given the new data. This process is summarised in Figure 2.

Figure 2 | Model building and prediction process

Our model uses six macroeconomic variables to predict sovereign credit ratings: GDP per capita, GDP growth, net general government debt/GDP, general government balance/GDP, narrow net external debt/current account receipts, and current account balance/GDP. We use data from 113 countries over the period 2015-2020 to train our model. This process enables us to build statistical parameters within which we can begin to make predictions around how changes in our variables will influence credit ratings.

BOX 2
How a random forest model works

Our statistical parameters are estimated by the random forest model. This model works by attempting to use the data given to explain why Country X has received a particular rating. The process works by first looking at which variable provides the best answer with the least amount of error. An example of this process is to consider a world wherein all adults drink black coffee, and all children drink fruit tea. If we were trying to obtain a variable which explained whether a person would drink black coffee or fruit tea, a person's age would provide the best answer with absolutely no error. In our situation, we have some countries with a value of GDP which is different to others, but they may still have the same rating. Furthermore, a country may grow slightly year on year and their rating may still not change. There are, however, predictable patterns across the whole scale. The process first attempts to find a variable which gives the best estimate with the least error; subsequent variables are then selected on an iterative basis which enable the process to narrow down on a specific outcome. This process continues until no further error can be eliminated.

There are four central benefits behind the implementation of a random forest model over other techniques:

First, we implement the above-described process thousands of times with slightly modified versions of the original data set, each making use of a varied pool of the original six variables. This means that our model, which we later use for prediction, will perform much better when presented with new data. This training of our model adds precision to our estimates that no parametric approach such as regression can offer.

Second, this approach enables us to model non-linearities with greater ease. Rating data is peculiar as it is discrete in nature (alphabetical ratings are translated into numerical scale such as the one we are using - AAA=20, AA+=19, SD=1 - with the AAA being the highest creditworthiness down to SD being the lowest). Incremental shifts through the rating scale do not represent equally meaningful changes in creditworthiness.
For instance, if Country X moves from one high grade rating to another on the scale (e.g. AAA to AA+), this change would not be comparable to a situation where Country X moved from a lower medium grade to a non-investment grade (BBB- to BB+).[2] Machine learning ultimately captures the dynamics of our variables with great accuracy and realism.

The third advantage of this approach relates to the fact that sovereign credit ratings are not characterised by the same distributional proper-ties we may observe in other variables. There are more observations at the top-end of the ratings scale than throughout the rest of the rating categories. These features make linear modelling of credit ratings difficult and subsequently lead to error.

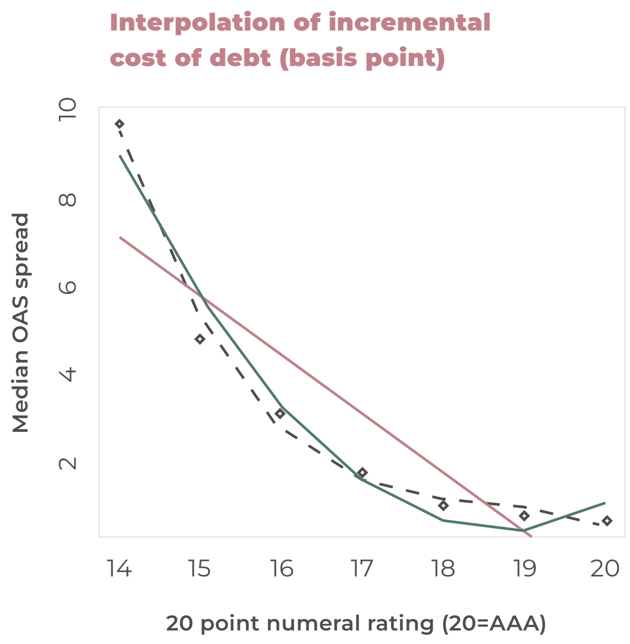
Finally, ratings are not merely quantitative assessments, and involve elements of subjective component which are difficult to be modelled using traditional approaches. Therefore, using methodology which can handle distributional properties, non-linearities, and qualitative components is essential.

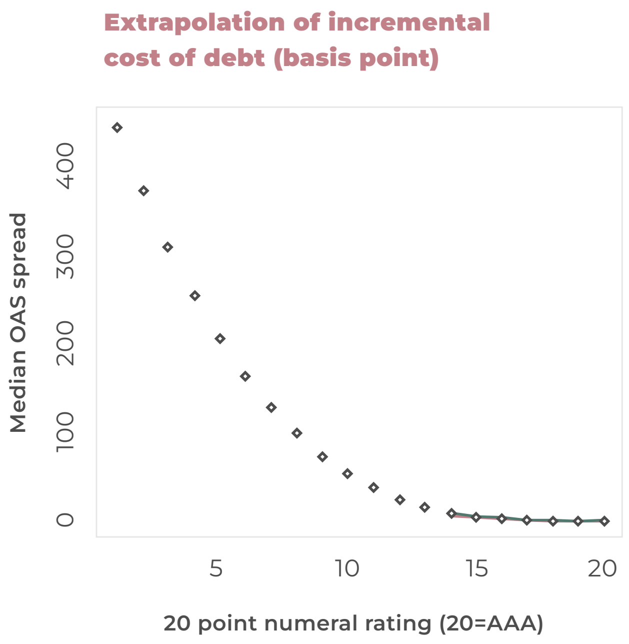
To adjust our macroeconomic data for changes in GDP we carry out basic calculations on historical GDP in order to convert the data. This process is relatively simple for the variables, GDP per capita and GDP growth. There is, however, more complexity when it comes to adjusting the government performance variables. In this instance, we estimate a relationship which describes how GDP losses (%) convert into changes in these variables. We do this with the help of data from S&P (2015). We are then able to use this statistical relationship, which is fitted with a high level of accuracy, to predict new values of our government performance variables. One exception to this procedure is the production of results for Madagascar. Madagascar is currently un-rated and access to data on its performance variables is limited. In this case we use the GDP per capita and growth data from the World Bank, and estimate its government performance variables based on the implied associations in the rest of the historical data. From this we also estimate its starting point credit rating using the same random forest model described above. We then feed this data back into our procedure and produce the results for biodiversity- respectively ecosystem services-adjusted credit ratings.

Once we obtain the biodiversity-respectively ecosystem services-adjusted credit ratings we can translate them into additional costs of borrowing of sovereigns and corporates. We do this using two methods. Firstly, following Klusak et al. (2021) we estimate the additional cost of servicing sovereign debt. It is established in the literature that sovereign downgrades increase sovereign cost of borrowing (Almeida et al. 2017). There are even direct translations of this relationship,[3] whereby a downgrade by one notch leads to X amount increase in sovereign yield spread. We take these estimations for a lower and higher bound, and multiply them by the number of notches a country will be downgraded as a result of biodiversity or ecosystem service loss, and by the amount of outstanding debt it holds. The amount of outstanding debt is available from S&P Sovereign Ratings Indicators. Additionally, since sovereigns impose a direct ceiling and spill over onto other assets classes incorporated in the country (banks, corporations),[4] we are able to translate the effect of sovereign changes into corporate cost of debt. Once again, we provide lower and higher bound estimates. The outstanding corporate debt is accessed through Bank of International Settlements (BIS).[5]

The second method of calculating cost of debt relies on option-adjusted spreads. This data provides the interest cost for each rating category applicable to sovereigns, over and above the risk-free rate. This data, taken from the Federal Reserve, provides us with the additional interest cost for AAA through to CCC.[6] Here we take the spread increase for the downgrade we estimate in an earlier step and multiply it through by the sovereign gross debt. For the spreads, we take the median spread for the ratings given (which vary between AAA to CCC), which allows us to use a value slightly lower than the mean and gives us a lower bound. We then interpolate the data to produce a function which will be the best at describing a relationship between ratings and spreads (namely we fit a 3rd level polynomial; see the left panel of Figure 3). Once that function is established, we take it and plug our estimates for the downgrades under the nature loss scenarios and the baseline scenario (without nature loss).[7] Following this we calculate the difference in spreads between the two scenarios, which represent an increase in the cost of debt due to nature loss. Cost of debt amounts to the change in the spread divided by 10,000 and multiplied by the amount of outstanding debt. Once again taking data from the BIS, we are also able to produce a similar calculation for the impact these downgrades could have on corporate debt within the country.

Figure 3 | Interpolation and extrapolation of incremental cost of debt





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Results

In the following, we discuss the empirical findings of our model when feeding in data for the World Bank's partial collapse of ecosystem services scenario and the business-as-usual scenario (which captures a gradual nature loss at current rates) and compare these with ratings and probabilities of default under the no-nature loss scenario. Of course, the model can be also used to estimate the effects on sovereign credit ratings for alternative scenarios. o simplify the discussion, we focus first on impacts on sovereign ratings (Section 5.1), before assessing biodiversity-adjusted probabilities of default in Section 5.2. Section 5.3 describes impacts on the changing cost of capital.

5.1 Biodiversity-adjusted sovereign credit ratings

Figure 4 provides an overview of the ratings implications for 26 sovereigns in the scenario of a partial collapse of ecosystem services and the business-as-usual scenario.[8] A first thing to note is that the estimated downgrades under the partial ecosystem services collapse scenario are much larger for most countries than under the business- as-usual scenario. Indeed, business-as-usual would result in a downgrade of one notch or more for only four of the 26 sovereigns by the year 2030, while 15 sovereigns would face a downgrade of one notch or more – and in many cases much more – under partial ecosystem services collapse. Interestingly, China and Indonesia are the two countries that would face the largest downgrades under the business-as-usual scenario, each with downgrades of approximately two notches.

For the partial ecosystem services collapse scenario, we see a wide variety of outcomes across the sample. Some countries such as Poland, Russia or Japan would feel no impact on their sovereign ratings at all. For a few others, including the United States and Canada, the potential impact is so small that it is unlikely to lead to a rating change (the simulated rating change is less than 0.5 notches). At the opposite extreme, we observe Asian economies such as China and Malaysia whose rating might fall by more than six notches in the partial collapse of ecosystem services scenario. This is an extremely significant downgrade prospect. To illustrate this case, consider Malaysia, currently rated A- by S&P. A nearly seven-notch downgrade would bring the rating to B+, four notches below investment grade. Between 1975 and 2020, less than 1% of A-rated sovereigns experienced a downgrade so deep within a 10-year time horizon (S&P Global 2021b). Crossing from investment- to speculative-grade would have potential serious regulatory implications.[9] No less than eight sovereigns (31% of the sample) would face their rating being lowered by more than three notches in the partial ecosystem services collapse scenario.

Figure 4 | Rating changes due to partial nature collapse and gradual nature loss at current rates under business-as-usual (in notches)

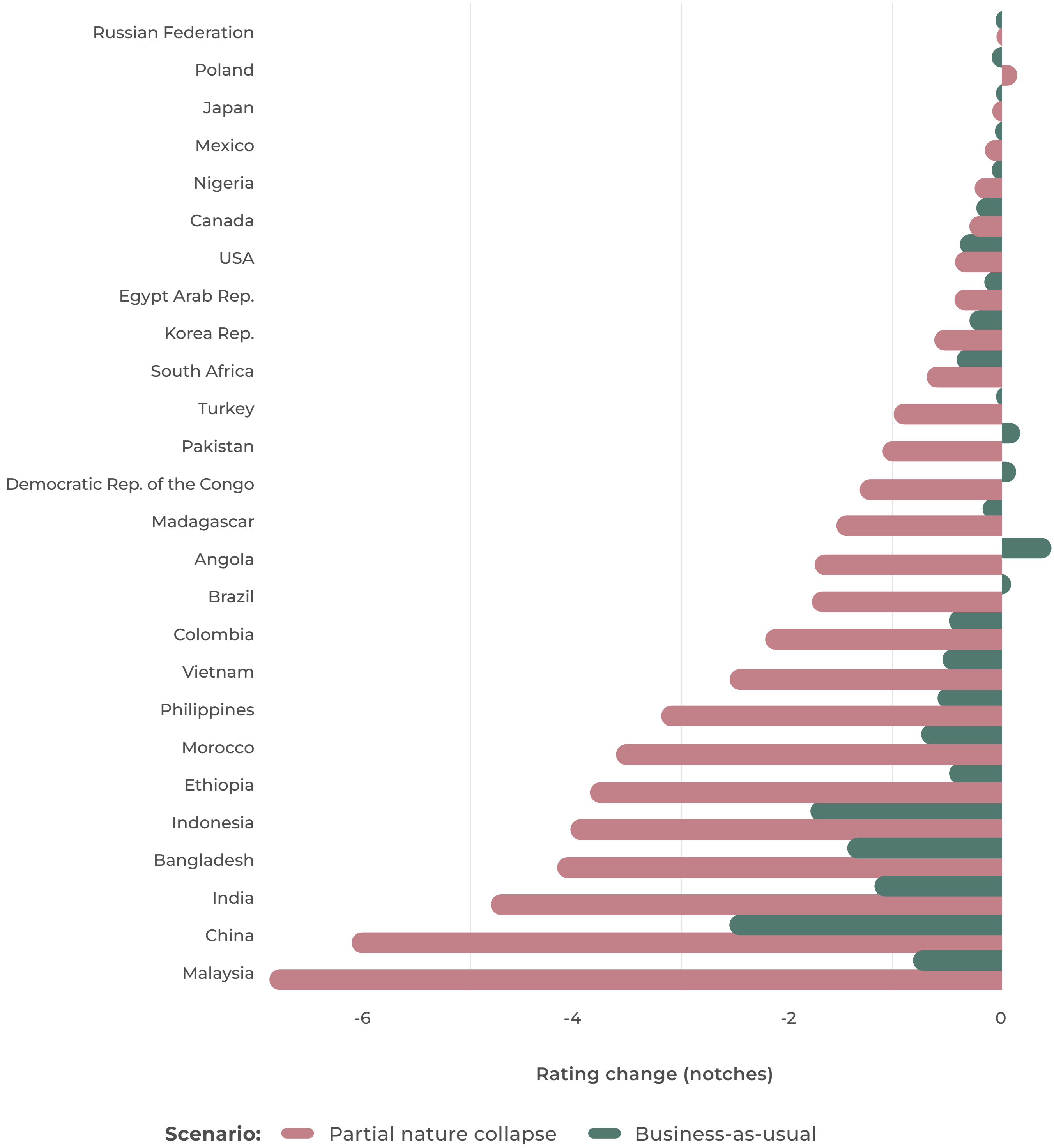


Figure 5 elaborates on the rating changes that would result from a partial ecosystem services collapse scenario and shows the pre- and post-shock sovereign ratings. The y-axis indicates the credit rating score (20-notch scale, with 20 being equivalent to AAA, and 10 or below being equivalent to a speculative rating). The green dot represents our baseline estimation of the credit rating; the red dot represents the biodiversity-adjusted credit rating. In addition, for each estimation we also present an error bound. That is, for each red dot there is an accompanying red line which reaches above and below to varying extents. This line represents our level of statistical confidence for this estimation.

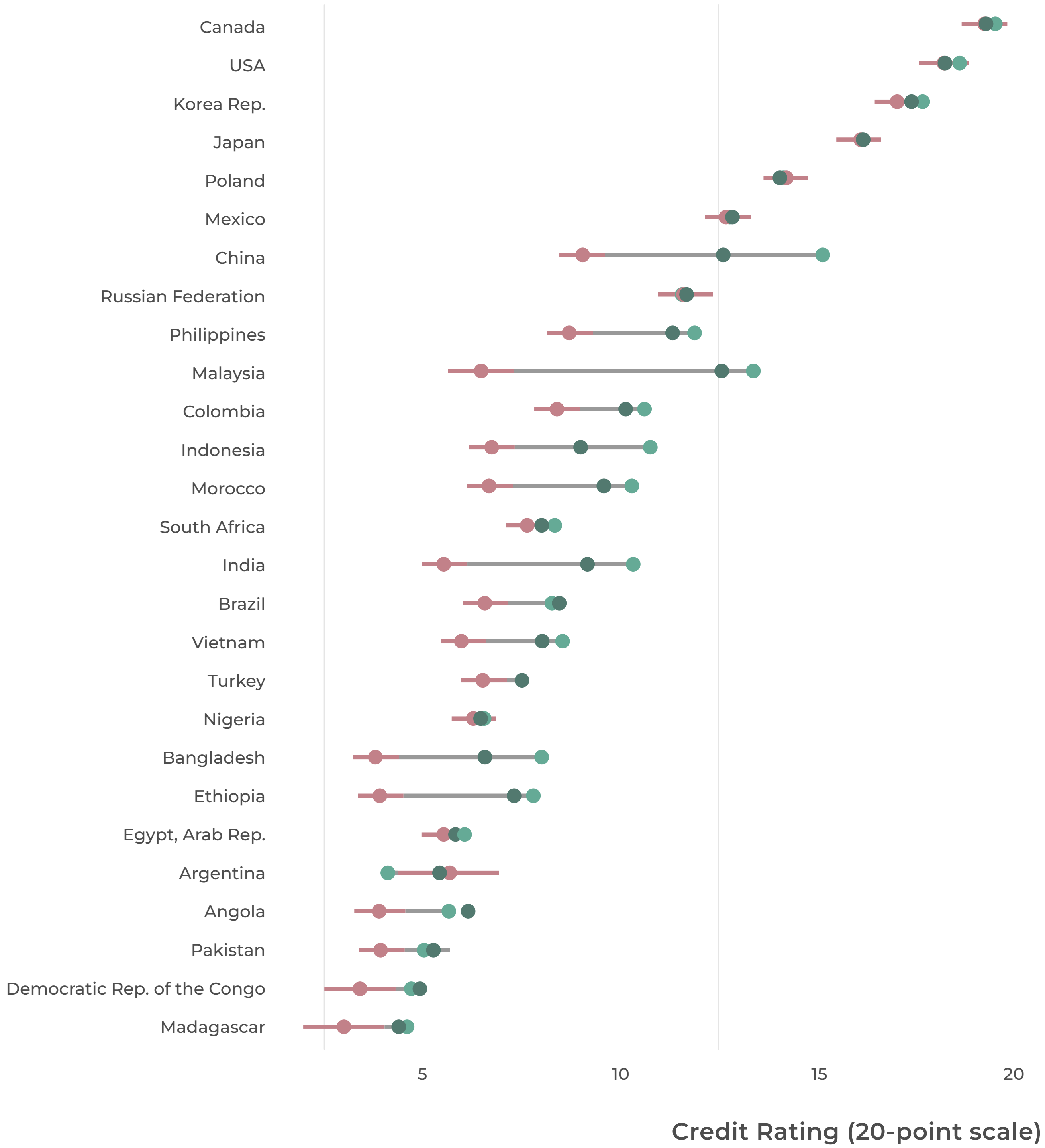
For highly rated sovereigns shown at the top of Figure 5, the estimated rating changes are generally small and within the margins of error. The first conclusion is therefore that a hypothetical world of a partial collapse of ecosystem services (as modelled by the World Bank) would most directly impact the creditworthiness of lower rated sovereigns in emerging and developing countries.

This is not entirely surprising, given that the purely economic dependency on biodiversity and ecosystem services (BES) tends to be greater for developing countries than for high-income economies, because of a higher contribution of those sectors to the economy which comparatively depend much stronger on nature's services (Retsa et al. 2020). It should be emphasised, however, that according to the Swiss Re Institute BES Index (Retsa et al. 2020), half of the top 20 countries with the highest share of fragile BES state (ecosystem services with a comparatively low capacity) are high-income countries (Malta, Israel, Bahrain, Cyprus, Greece, Australia, Singapore, Spain, Belgium and Italy) – none of which were included in the World Bank analysis.

While the GDP dependency of these countries on BES tends to be smaller, it is not negligible, and given the already fragile state respectively low service capacity of large shares of their ecosystems, the risk of partial ecosystem collapse for these countries is comparatively high.

Future research should model potential output losses related to the collapse in the provision of selected ecosystem services that are particularly important to these and other high-income countries, so that potential credit rating changes can be examined also for these countries.

Figure 5 | Pre- and post-shock sovereign ratings under the partial nature collapse scenario

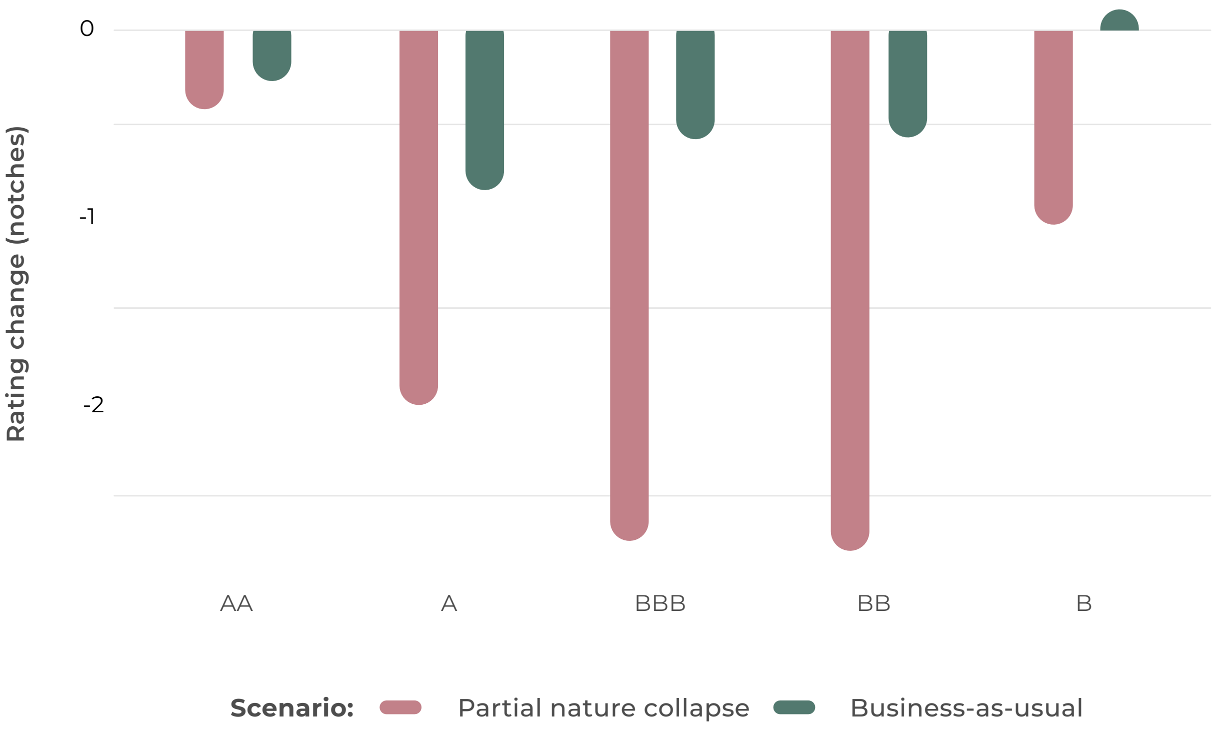


Nonetheless, our present set of results clearly suggests a greater impact on the creditworthiness of lower rated sovereigns. This finding is further corroborated in Figure 6, which shows the relationship between average rating changes and the estimated initial rating category in 2020. There is no discernible rating impact for sovereigns that currently have a rating in the AA and AAA categories. Sovereigns starting off in the BBB and BB categories will face the hardest hits with downgrades averaging almost three notches. At the lower end of the spectrum, in the B category, the ratings impact seems less severe. This observation does not suggest that the lowest rated sovereigns have little to worry about when it comes to depletion of their natural resources.

The reason for the relatively low average downgrade intensity is directly related with a technical ratings issue. Ratings are an ordinal ranking of credit risk and not a cardinal ranking. Credit risk does not rise and fall proportionately as we move along the rating scale.[10] Instead, as ratings move down the scale default probabilities rise exponentially.

For historical reasons (initially only highly creditworthy issuers were seeking a rating) there is far more granularity at the top of rating scale than at the very bottom. In other words, a sovereign with a very low rating in the B category does not have much capacity to go down even further when its credit fundamentals worsen. That is why ratings tend to be stickier in the B category.[11] It takes a bigger shift in fundamentals to move these rating categories than others. This can explain why sovereigns starting off in the B category appear to be better shielded from downgrades.

Figure 6 | Average rating change by rating category (in notches, classified by 2020 estimated rating)



5.2 Biodiversity-adjusted default probability

To partly correct for this technical bias that underestimates the impact on creditworthiness for lower-rated sovereigns, we convert the alphabetical ratings into empirically observed probabilities of default (PD). Rating agencies publish on an annual basis default and transition statistics for all asset classes, including sovereigns. In those publications the agencies described how the ratings have performed over time. In doing so they apply different time horizons, with five and 10 years being the most commonly used.

A transition table would follow the ratings changes off a static pool of ratings over the defined time horizon, say 10 years. For example, they look at all issues that were rated BBB on 1 January 1990. They then follow this static pool of BBB rated sovereigns to determine, which percentage has defaulted within the 10-year horizon. This exercise is repeated for every year, i.e. 1991, 1992, and so on. At the end they calculate the average of the percentage of defaulted issuers within the time horizon over all those static pools. This results in what is generally referred to as a BBB default probability. This default probability is not the ratio that rating agencies would deliberately target. Instead, it is the outcome of historical observations. Depending on the credit cycle, the percentage of defaulted sovereigns will vary between the different static pools. The BBB default probability is simply the average over longer time horizons. In the case of S&P, the average is calculated for the period 1975 to 2020. Ideally, the default probability would increase as the rating of different static pools declines. Given the relatively small universe of default observations for sovereigns, there are discreet jumps, however. This means that, against expectations, the probability of default could drop if we move down one notch. For classes with much larger number of issuers, such as corporates, such kinks are uncommon.

To correct for such outliers along the rating scale, we complete a best fit interpolation to create a monotonically rising probability of default as we move down the rating scale. Figure 7 shows the rating on the x-axis and the default probability on the y-axis. The red, blue and dotted black line represent a linear, 2nd order and 3rd order polynomial respectively. The third order provides the best fit and any further terms do not provide a statistically significant ‘better’ fit. The equation representing the third order polynomial interpolation is then applied to assign smoothed (or ‘unkinked’) default probabilities to each rating level.

It is important to understand that the change of the probability of default does not relate to the rating in a linear fashion. The probability of default increases exponentially as we move down the rating scale, and especially so once we cross into speculative grade ratings, i.e., ratings in the BB category or below.[12] With this smooth default probability curve, we can then convert rating changes into changes of default probability at every rung of the rating ladder.

Figure 7 | Relationship between probability of default and ratings

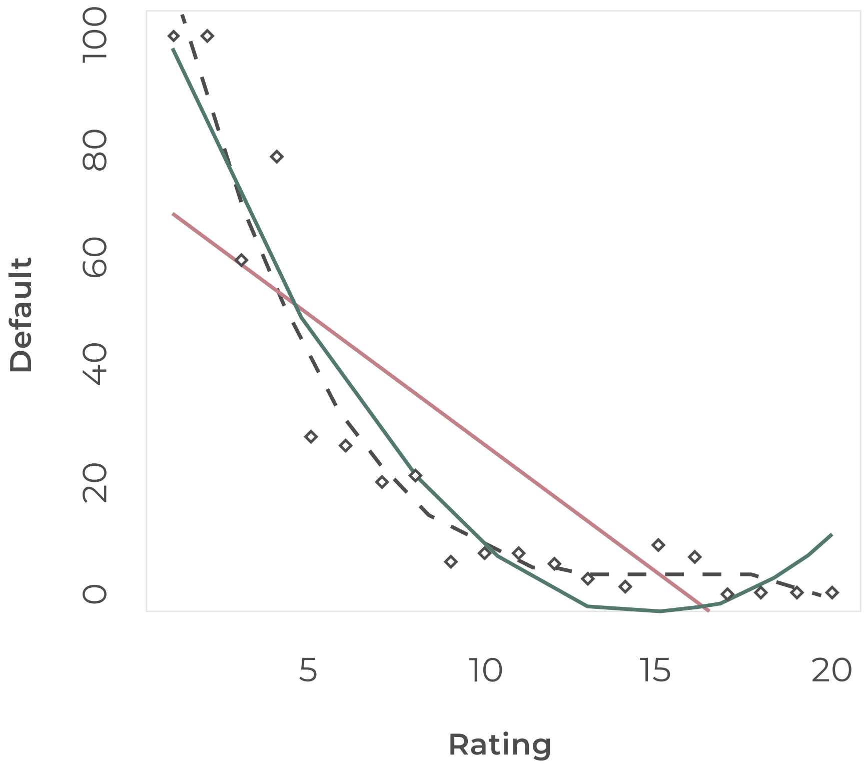


Figure 7 describes the relationship between sovereign ratings (x-axis) and the probability of default (y-axis). The purpose of this exercise is to create an equation that converts ratings downgrades into changes in PD. We begin by plotting rating-PD pairs (the dots), which show PD at various points along the rating scale. Next, we try to identify an equation that best describes the distribution of those dots. First, we try a straight line (red), but it is not a good fit. By adding another term (formally, introducing a higher-order polynomial) we allow the equation to curve (blue line). This provides a better fit than the straight line, but adding yet another order (dashed line) improves the fit even further. We then use this equation to convert predicted ratings changes into predicted PDs.

Figure 8 shows how the likelihood of default differs across rating categories. As expected, we can see the vulnerability of sovereigns rated in the speculative categories increasing further. The above-mentioned rating stickiness is reflected by a lesser effect of a partial collapse in ecosystem services on the probability of default in the B category compared to BB rated sovereigns. At the other end of the scale, Figure 8 demonstrates forcefully that risks to the ecosystem services considered by the World Bank are predominantly something for lower rated sovereigns to worry about. AAA or AA-rated sovereigns experience negligible risk to solvency, and even A-rated sovereigns appear resilient.

Figure 8 | Average probability of default change by rating category (in % points, classified by 2020 estimated rating)

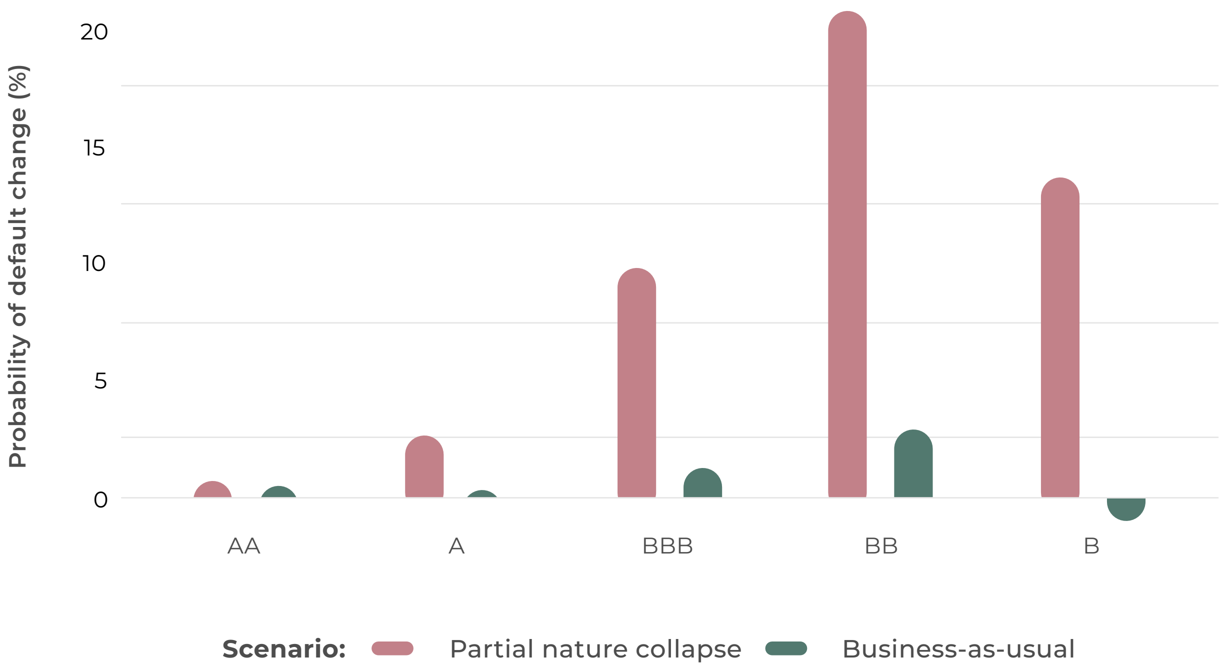


Figure 9 provides more PD detail on a country-by-country basis. There is no sovereign for which PD would increase under a partial ecosystem collapse as much as for Bangladesh (41%), with Ethiopia (38%) and India (29%) not far behind. Any PD increase above 10% should be considered substantial. 10% is currently in the range of the 10-year default probability of a BB rated sovereign. BB bonds are considered speculative investments. Adding speculative risks to an often already high PD to begin with poses significant solvency concerns. Six countries (Madagascar, DRC, Bangladesh, Angola, Ethiopia, and Pakistan) would default with a probability of over 50% in a partial ecosystem collapse scenario (Figure 10).

Figure 9 | Change in probability of default (% points)

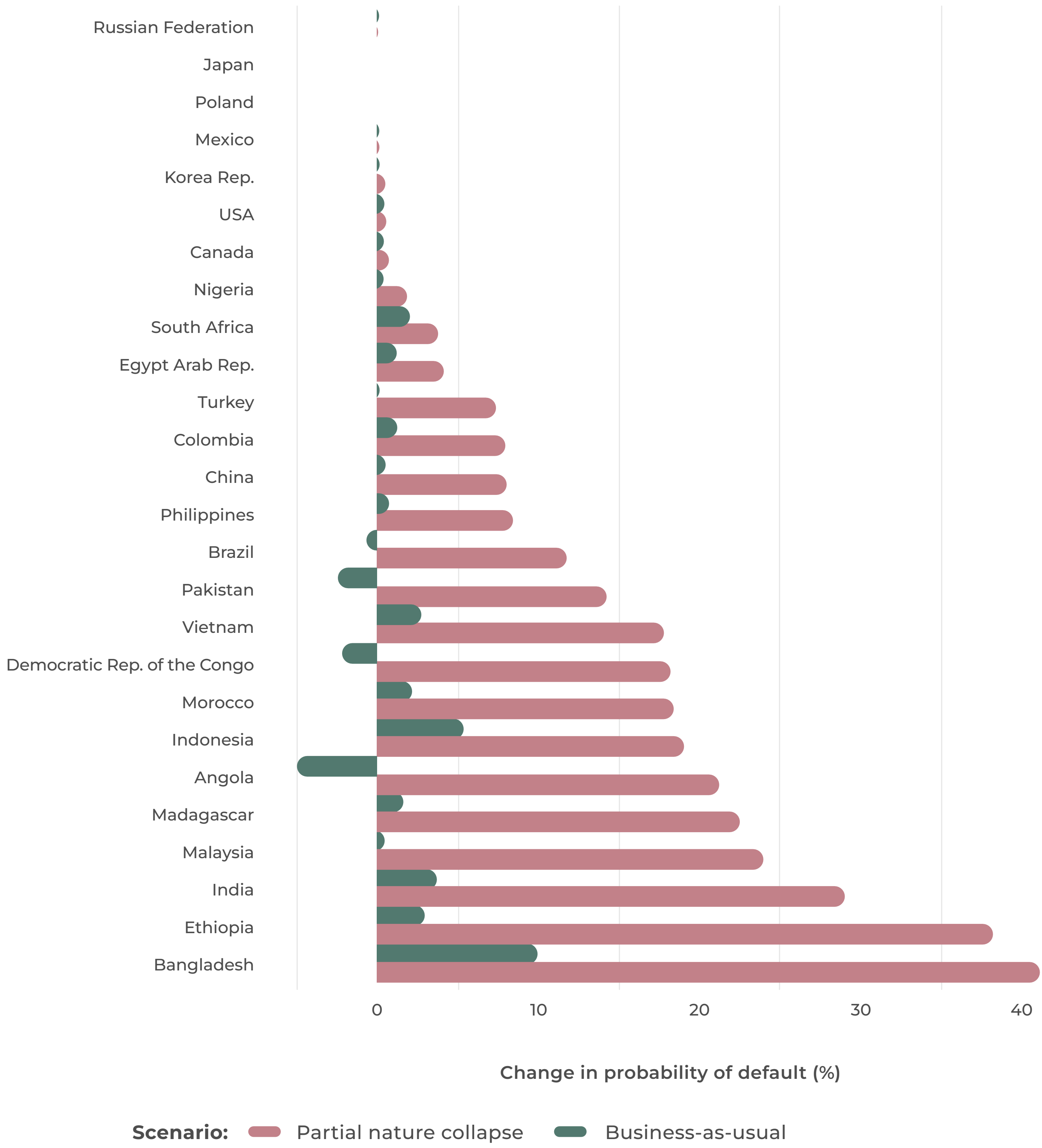


Figure 10 | Probability of default without and with partial nature collapse (%)

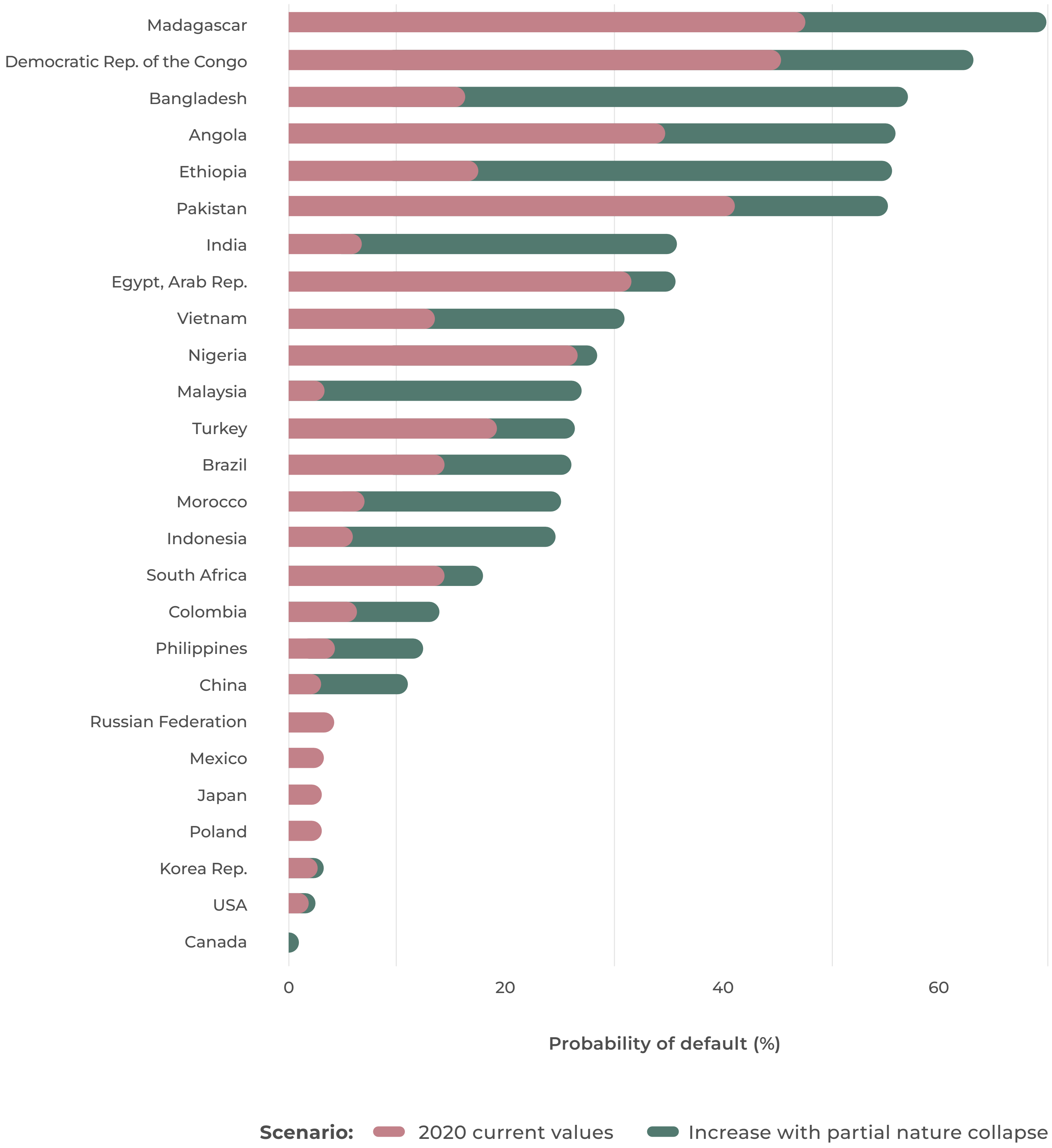
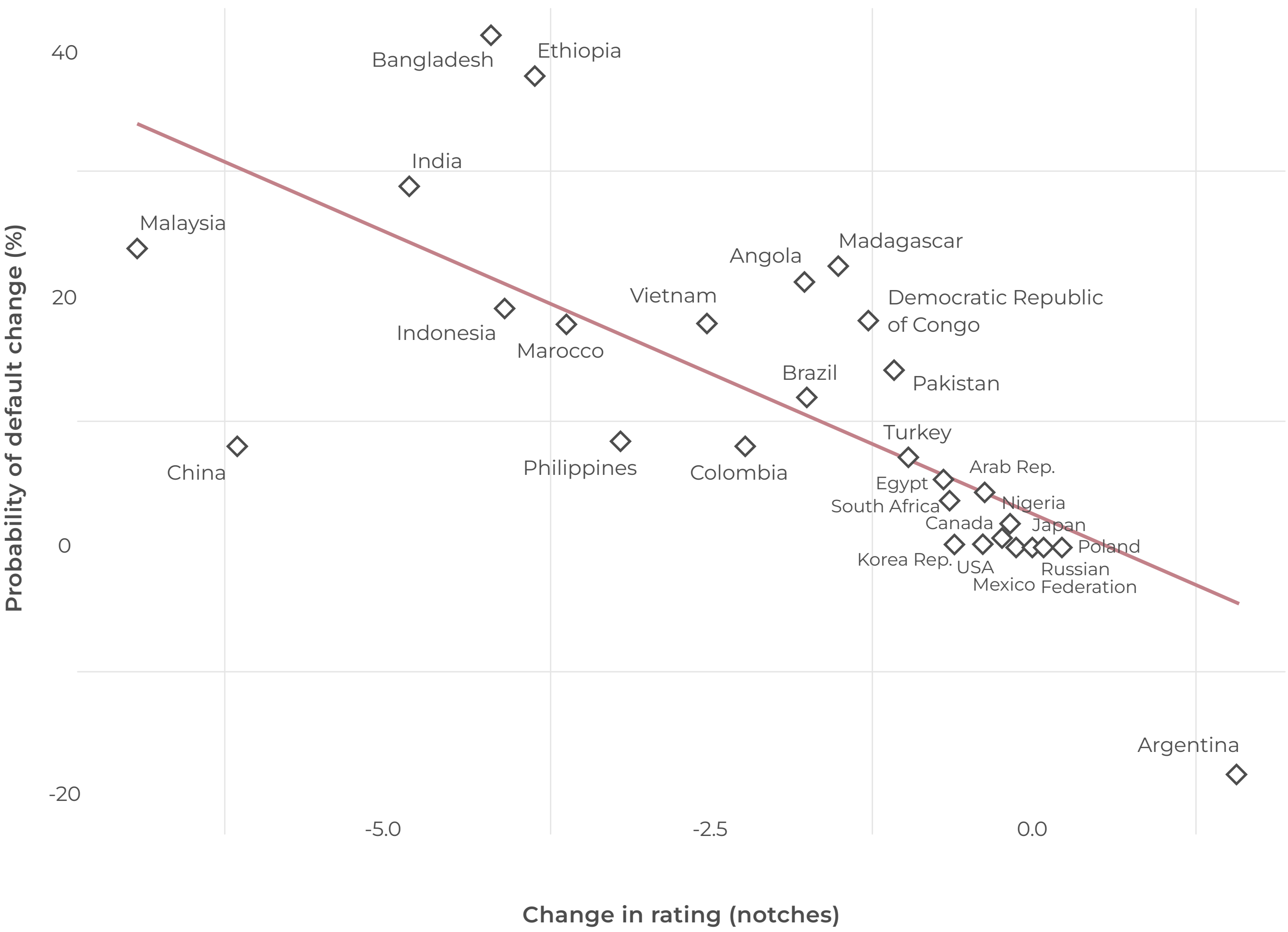


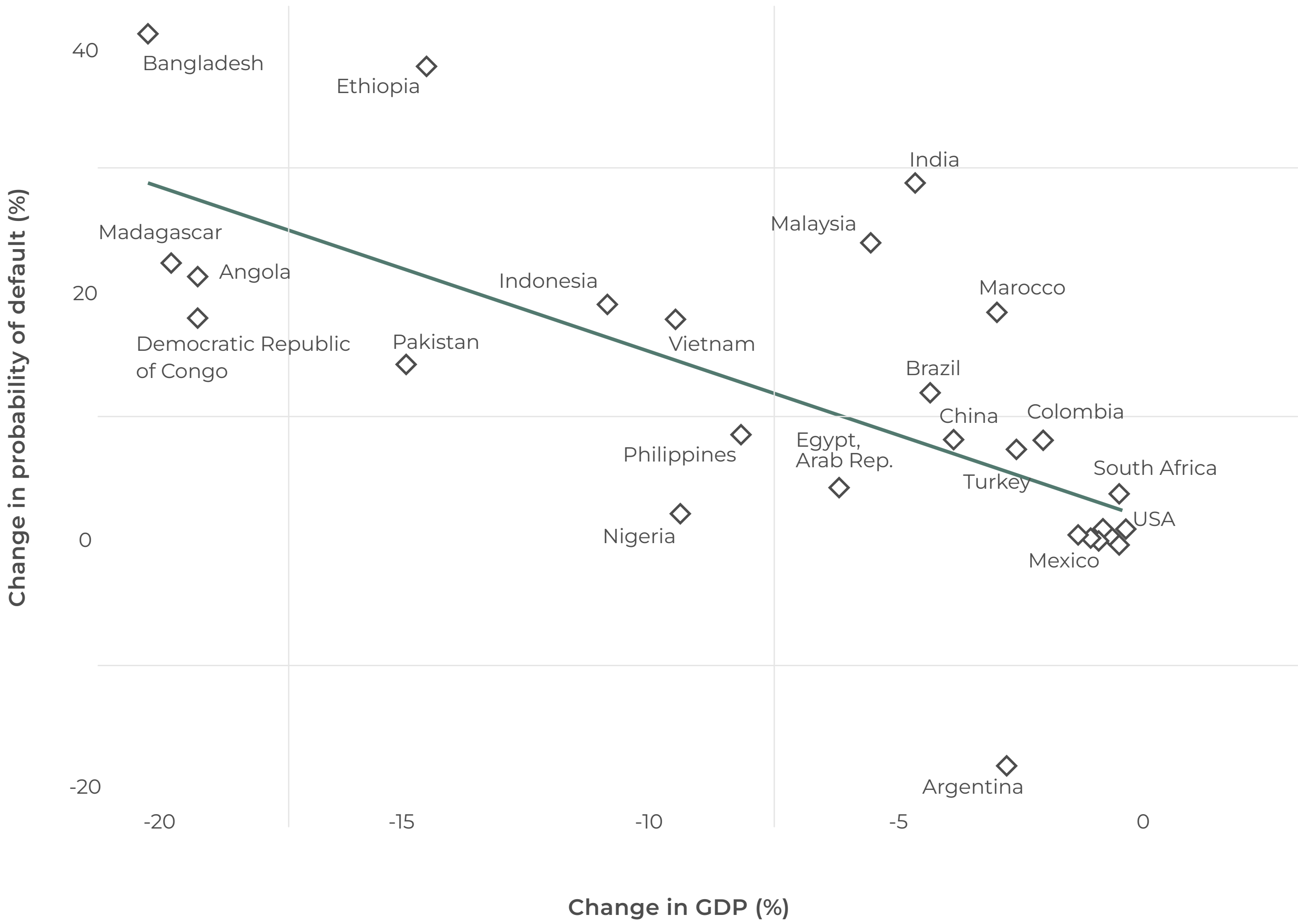
Figure 11 demonstrates that rating changes and PD changes are correlated, as one would expect them to be given that ratings are rankings of issuers with respect to agencies' opinions on PD. But while the correlation is there, it is not as tight as it would have been if ratings and PD expectations were moving proportionately rather than exponentially. Since ratings are nothing more than a shorthand understood by financial market participants to approximate PD, the fundamental underlying concern should be with PD. Ratings are merely PD proxies. For example, consider the two dots far below the line, China and Malaysia. They could be subject to downgrades of between six and seven notches as shown in Figure 4. That sounds dramatic, and indeed it is. But China's problem is not six times as dramatic as the situation in Pakistan, which can be expected to experience a one notch downgrade. In fact, as Figure 10 shows, the probability of default increases in Pakistan almost twice as much as it does in China. Why? Pakistan starts off with a rating that is 11 notches below China's. With a single notch downgrade, Pakistan therefore gets into a much steeper sloped PD curve than China.

Figure 11 Change in ratings (x-axis, notches) and change in probability of default (y-axis, %points) under the partial nature collapse scenario



Finally, Figure 12 illustrates that a positive relationship exists between the size of the GDP reduction caused by the nature shock on the one hand and the increase in the probability of default on the other. But there still can be wide differences between countries confronting a comparable economic shock. It is not enough to simply take the GDP loss under the nature loss scenario and apply some rule-of-thumb multiplier to obtain the change in PD. Country-specific circumstance can make a big difference, starting with the current rating level and how far along the exponential PD curve a sovereign is located, but also how close or far away the credit-fundamental variables are from thresholds that could move their rating and thus PD.

Figure 12 | Correlation GDP loss (x) and increase in the probability of default (y) under the partial nature collapse scenario



5.3 Biodiversity-adjusted cost of capital

Returning to our estimates of sovereign downgrades, induced by partial nature loss observed in Figures 4-6, we calculate their effects on the additional costs of borrowing incurred by sovereigns and corporates for the partial ecosystem collapse scenario. Figure 13 presents two charts which outline the costs calculated by the two distinct methods outlined earlier. In method 1 (left panel), we estimate a linear increase in cost of debt regardless of where we are on the rating scale. In method 2 (right panel), we use the option-adjusted spreads on debt instruments over the risk-free rate for different ratings. We then take the spread increase for the downgrade we estimate and multiply them by the sovereign gross debt.

We obtain similar results in both exercises, reassuring us about robustness of our estimates. The only exemption is the United States, which is an outlier in this exercise. The linear approximation (method 1) imposes a very high cost for only losing a marginal amount of incremental sovereign creditworthiness. This highlights a limitation in method 1. For the United States, it would be unrealistic to expect such a large increase in the cost of debt against a less than proportionate decrease in sovereign creditworthiness.

For example, in the case of China with a downgrade of approximately six notches, the knock-on effect on additional costs of borrowing is estimated at between $12-18 billion using method 1 and $17 billion using method 2. In terms of corporate debt, firms in China are estimated to incur an additional $20-30 billion using method 1 and $28 billion using method 2. Similarly affected is Malaysia with a nearly seven notches sovereign downgrade leading to an increase of sovereign debt between $1-1.6 billion (method 1) and $2.55 billion (method 2). Corporates in Malaysia would need to cover additional $1-1.5 billion ($2.3 billion) in interest expenses using method 1 (2) respectively.

Table 2 presents comparable results using two methods for all countries in our sample which are estimated to receive a downgrade larger than three notches. Table 3 presents the corresponding spill over effects on corporates in monetary terms. Although there are slight variations between the two methods, the overall picture is clear: Sovereigns and corporates will induce a significant cost due to nature loss.

Figure 13 | Cost of capital calculations using two methods for the partial nature collapse scenario (results for method 1: left panel; results for method 2: right panel)

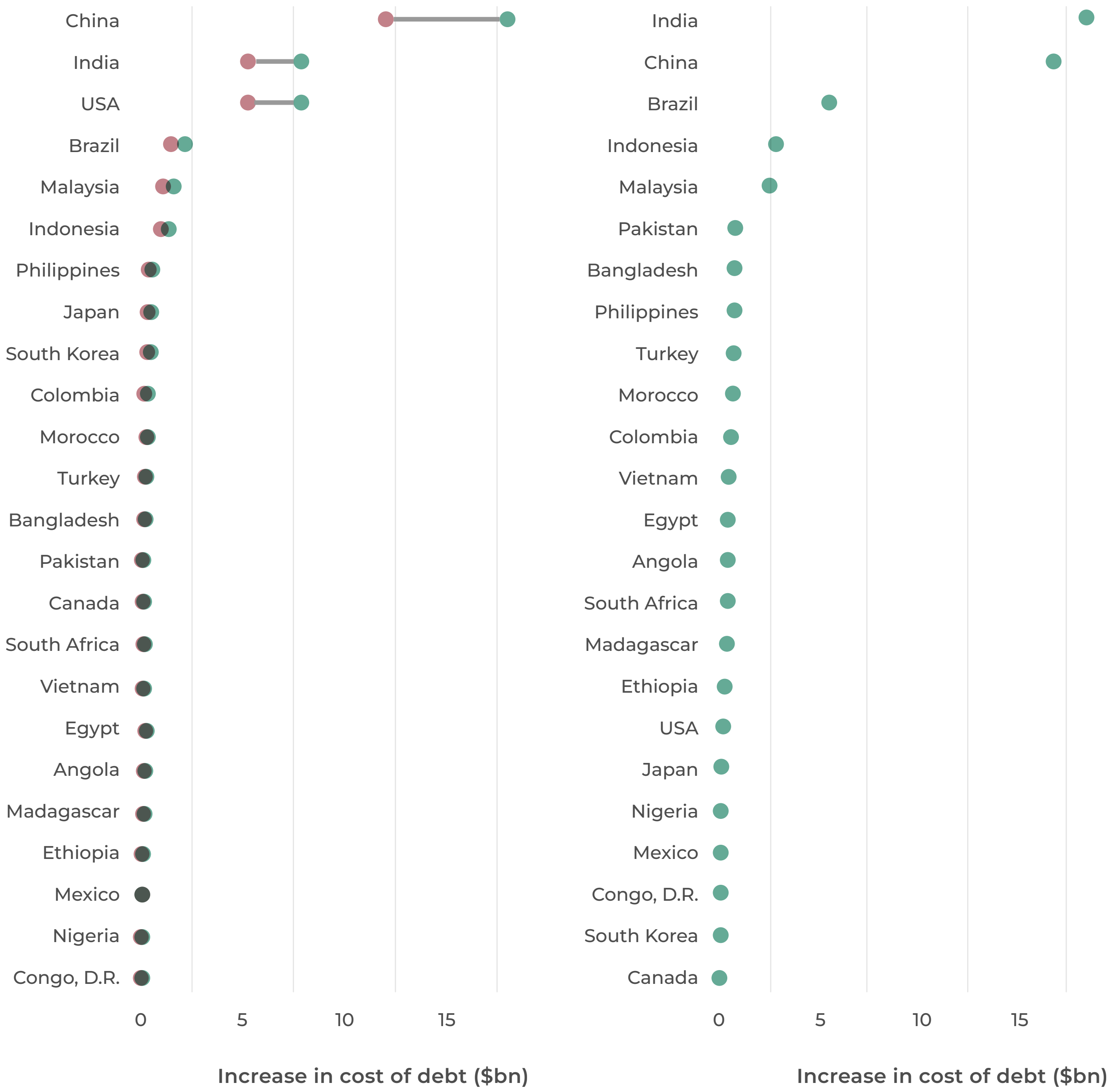


Table 2 | Additional cost of borrowing for most affected sovereigns in the sample under the partial nature collapse scenario

			METHOD 1		METHOD 2
Sovereign	**Sovereign downgrade (notches)**	**Outstanding sovereign debt ($ bn)**	**Cost of sovereign borrowing ($ bn) (lower bound)**	**Cost of sovereign borrowing ($ bn) (upper bound)**	**Cost of sovereign borrowing ($ bn)**
Philippines	3.18	134.50	0.34	0.51	0.73
Morocco	3.60	67.20	0.19	0.29	0.61
Ethiopia	3.86	13.50	0.04	0.06	0.21
Indonesia	4.05	290.60	0.94	1.41	2.83
Bangladesh	4.18	45.50	0.15	0.23	0.76
India	4.80	1365.30	5.24	7.86	18.56
China	6.11	2464.40	12.05	18.07	16.85
Malaysia	6.90	189.80	1.05	1.57	2.56
Full sample total	**2.19**	**35340.78**	**28.40**	**42.60**	**52.89**

Notes: We are translating the biodiversity & ecosystem services induced sovereign downgrades into increased costs of sovereign debt. Only sovereigns with downgrades greater than three notches are presented here. Data available from S&P Sovereign Ratings Indicators. For further details on the methodology see Section 4.

Table 3 | Additional cost of corporate debt due to nature loss-induced sovereign downgrades under the partial nature collapse scenario

			METHOD 1		METHOD 2
Sovereign	**Sovereign downgrade (notches)**	**Outstanding corporate debt ($ bn)**	**Cost of corporate borrowing ($ bn) (lower bound)**	**Cost of corporate borrowing ($ bn) (upper bound)**	**Cost of corporate borrowing ($ bn)**
Philippines	3.18	14.00	0.04	0.05	0.08
China	6.11	4061.00	19.86	29.78	27.77
Malaysia	6.90	176.00	0.97	1.46	2.37

Notes: We are translating the biodiversity & ecosystem services induced sovereign downgrades into increased costs of corporate debt. Only sovereigns with downgrades greater than three notches and with data on outstanding corporate debt from the BIS are presented here. For further details on the methodology see Section 4.

6

Conclusion and policy recommendations

Biodiversity loss and environmental degradation can have material impact on sovereign risk and credit ratings. This report has estimated for the first time the credit ratings implications for sovereigns in the case of a partial collapse of ecosystem services as well as of a gradual nature loss at current rates under a business-as-usual scenario.

It should be emphasised that due to the particular countries in our sample and specific ecosystem services analysed, our results provide only a partial estimate of the effects of nature-loss on sovereign debt markets. In particular, we are unable to include air quality in the current analysis, which has a direct effect on health, human capital formation, and labour productivity. Similarly, soil health is not included, which impacts agricultural productivity. The effects of biodiversity loss on many high income countries are also more difficult to assess. While the GDP dependency of these countries on biodiversity and ecosystems services tends to be smaller than in developing countries, it is not negligible, and given the already highly depleted status of their ecosystems, the risk of partial ecosystem collapse for these countries is comparatively high. Future research should model potential output losses related to the collapse in the provision of select ecosystem services that are particularly important to these and other high-income countries so that potential credit rating changes can be examined also for these countries.

Our findings have three important implications for stakeholders including credit rating agencies, investors, and sovereigns themselves.

First, given the likely impact of nature loss on output, sovereign ratings and PD, credit rating agencies ought to explicitly include these risks into their ratings methodologies. Conceptually, incorporating biodiversity- and nature-related risks into sovereign ratings is no different from incorporating other highly uncertain risks such as geopolitical risk. Indeed, the risk of biodiversity loss can be precisely quantified and geographically localised. Given the potential size of the related economic risk for individual sovereigns, the inclusion of nature risks into sovereign risk frameworks is not only expedient, but inevitable.

Second, investors who rely on nature-blind measures of creditworthiness will be unable to correctly identify, price, and manage risk across their portfolio. Backward-looking risk assessments are insufficient. Whilst it is important to acknowledge that nature loss and climate change have already begun to impact the cost of borrowing for some sovereigns, investors should apply forward-looking risk metrics that address forthcoming risks based on the best possible science.

Third, there is a strong economic rationale for governments to take forceful action to stop the depletion of the natural habitat on which their economies are based. The cost of inaction is high. A continued depletion of nature and biodiversity would increase the risk of partial nature collapse, with potentially significant downside risks in terms of output losses, ratings downgrades, and a resulting higher cost of capital. Investors are beginning to take note of nature and biodiversity risks, and are increasingly under pressure from civil society to not invest in environmentally problematic assets. This could increase the cost of capital for sovereigns that don't mitigate nature- and biodiversity-related risks already in the short term.

While a continued depletion of natural capital will likely result in output losses and downgrades, those countries effectively protecting or even enhancing their biological assets could in principle see their creditworthiness improved, because the loss elsewhere makes their conserved natural assets globally scarcer and thus potentially more valuable. Explicitly incorporating nature risk in sovereign credit ratings – and recognising efforts to protect nature – would create a strong incentive for governments to enhance environmental protection.[13] Innovative debt instruments such as sovereign sustainability/nature-linked bonds could further incentivise governments to raise their ambitions regarding nature and other sustainability goals and potentially lower the cost of sovereign debt (Volz 2022). The hope, as put by Caputo Silva and Stewart (2020) is that "financial markets may 'reward' countries meeting ambitious [sustainability] targets with lower-cost debt." Favourable financing conditions for sovereign sustainability/nature-linked bonds may also be achieved through credit enhancements provided by international financial organisations (Volz et al. 2021).

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Endnotes

[1] According to the Bank of International Settlements' Debt Securities Statistics (https://stats.bis.org/statx-/srs/table/c1), global government debt amounted to $64 trillion at end-June 2021, out of a total of $125 trillion of all bonds outstanding. Corporate issuers amounted to $17 trillion and financial institutions for $44 trillion.

[2] Following Klusak et al. (2021) we apply conversion of 0.08% for lower bound and 0.12% for higher bound for sovereigns. Furthermore, we apply 0.048% (0.084%) conversion for lower (higher) bound for corporates.

[3] As seen during previous sovereign debt crisis, sovereign downgrades can spill over to other nations. Additionally, sovereigns impose a direct cap on ratings of other assets meaning that other issuers are unlikely to receive a rating higher than that of their sovereign.

[4] Note that the effect on corporate debt cannot be established for some nations as data is not available for them.

[5] Data is accessed through FRED database accessible from https://fred.stlouisfed.org.

[6] We extrapolate the values of the ratings scale which are not observed in our dataset using this function (right panel of Figure 3).

[7] We excluded the case of Argentina because the random forest model is not able to estimate with an acceptable degree of precision the sovereign's rating. The reason is that Argentina's current rating is far lower than its economic and financial fundamentals would suggest. This very low actual rating is the result of the country's history as a serial defaulter, which is not visible in the financial and economic variables, but which is taken into account by CRAs.

[8] In some jurisdictions (e.g. Czech Republic, Korea, Mexico and Pakistan) specific investors (e.g. banks or institutional investors) are prohibited from holding speculative grade investments or face higher capital requirements if they do (Çelik et al. 2020).

[9] This implies that the creditworthiness does not move linearly with the probability of default. Therefore, if Country X is downgraded by one notch it does not infer an equivalent effect on probability of default to what Country Y might experience.

[10] According to transition data by S&P Global (2021b, Table 39) spanning 1975-2020, 17.1% of all sovereigns rated B-, B, or B+ still had the same rating 10 years later. That proportion is lower for sovereigns rated in other categories except for the ones at the top of the scale. The corresponding numbers for BB, BBB, and A are 10.2%, 15.8% and 14.3%, respectively.

[11] This is also due to expectations towards default made by market actors who perceive the signalling of the downgrading.

[12] As pointed out recently by the World Bank, while greater transparency around climate and sustainability risks "could lead to an increased perception of risk in some countries, it is also possible that reporting could decrease the perception of risk if it is able to effectively integrate adaptation and resilience criteria into financial market analysis" (Stewart et al. 2022).

Appendix

Conversion of alphabetical S&P's sovereign ratings to 20-notch scale

Long-term Foreign currency issuer rating symbol	Numerical rating	Rating grade	
S&P			
AAA	20	Prime high grade	Investment grade
AA+	19	High grade	
AA	18		
AA-	17		
A+	16	Upper medium grade	
A	15		
A-	14		
BBB+	13	Lower medium grade	
BBB	12		
BBB-	11		
BB+	10	Speculative	Non- investment grade
BB	9		
BB-	8		
B+	7	Highly speculative	
B	6		
B-	5		
CCC+	4	Substantial risks	
CCC	3		
CCC-	2		
CC	1	Extremely speculative	
C	1	In default	
D/SD	1		

Notes: This table presents S&P alphabetical categories translated into 20-notch scale based on S&P's Global Rating Definitions available from

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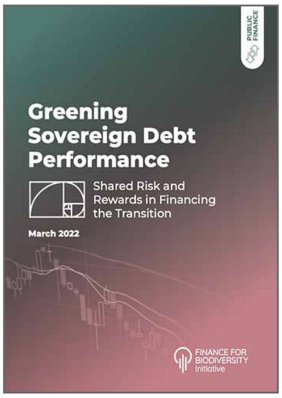

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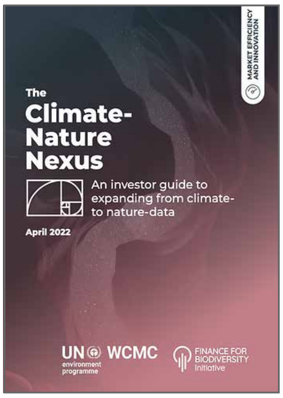

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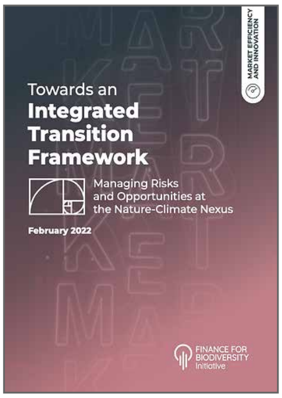

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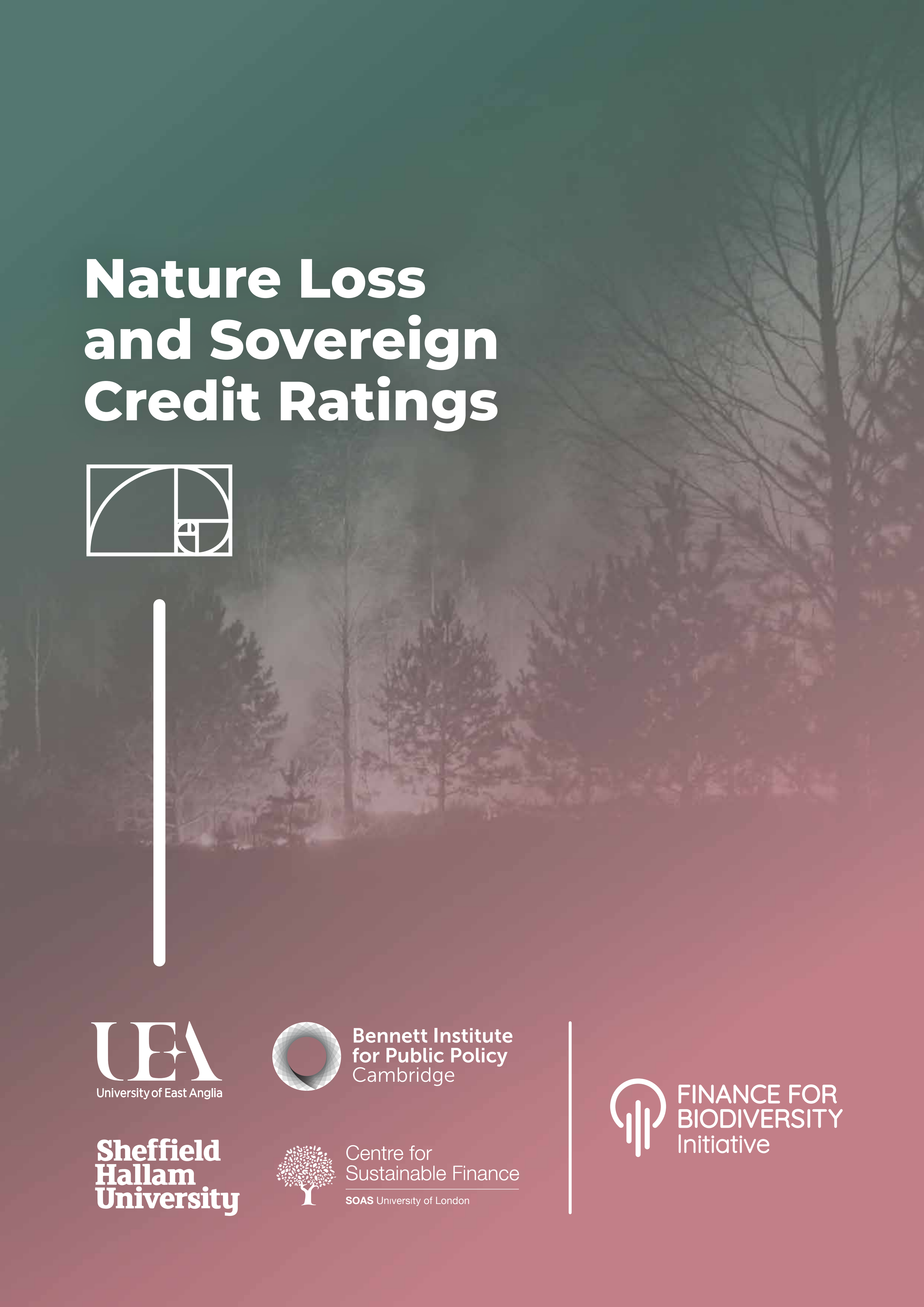

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