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Nature Loss and Sovereign Credit Ratings

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Executive summary

Biodiversity loss and 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.

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. However, that uncertainty is not fundamentally different from the uncertainties surrounding issues of geopolitical risks or contingent liabilities.

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.

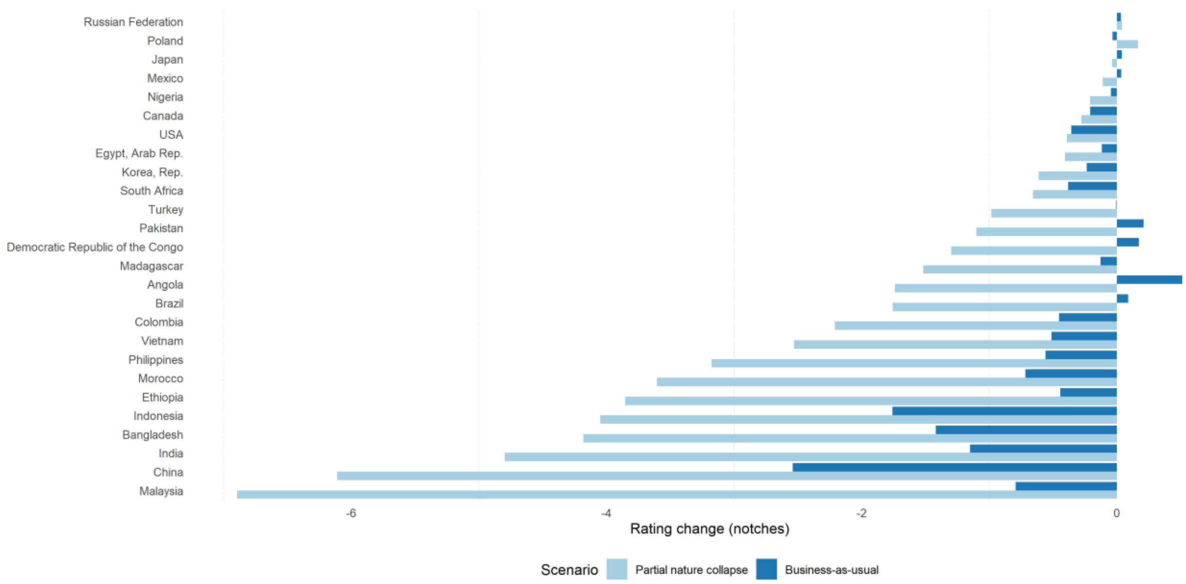
Using the most advanced AI methodology, this report models the effect of nature loss on credit ratings, default probabilities, and the cost of borrowing for 26 sovereigns. We estimate these effects under multiple scenarios describing the trajectory of nature decline: a 'status quo' scenario, in which nature-loss is halted and there is no further decline; a business-as-usual scenario in which current trends of nature-loss continue; and a 'partial nature collapse' scenario, in which continued degradation leads to ecological tipping points (i.e. ecosystems collapse). Using 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. While some countries would see little or no impact, some face prospects of significant downgrades.

Figure ES1 shows that the estimated downgrades under the partial nature collapse scenario are much larger for most countries than 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 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.

For the partial ecosystem services collapse scenario, 15 out of 26 sovereigns (58% of the sample) would face a downgrade of one notch or more, resulting in approximately $28-53 billion in additional costs of interest payments borne by these nations. But we see a wide variety of outcomes across the sample. About a third of the sovereigns (31% of the sample) would see their rating being 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.

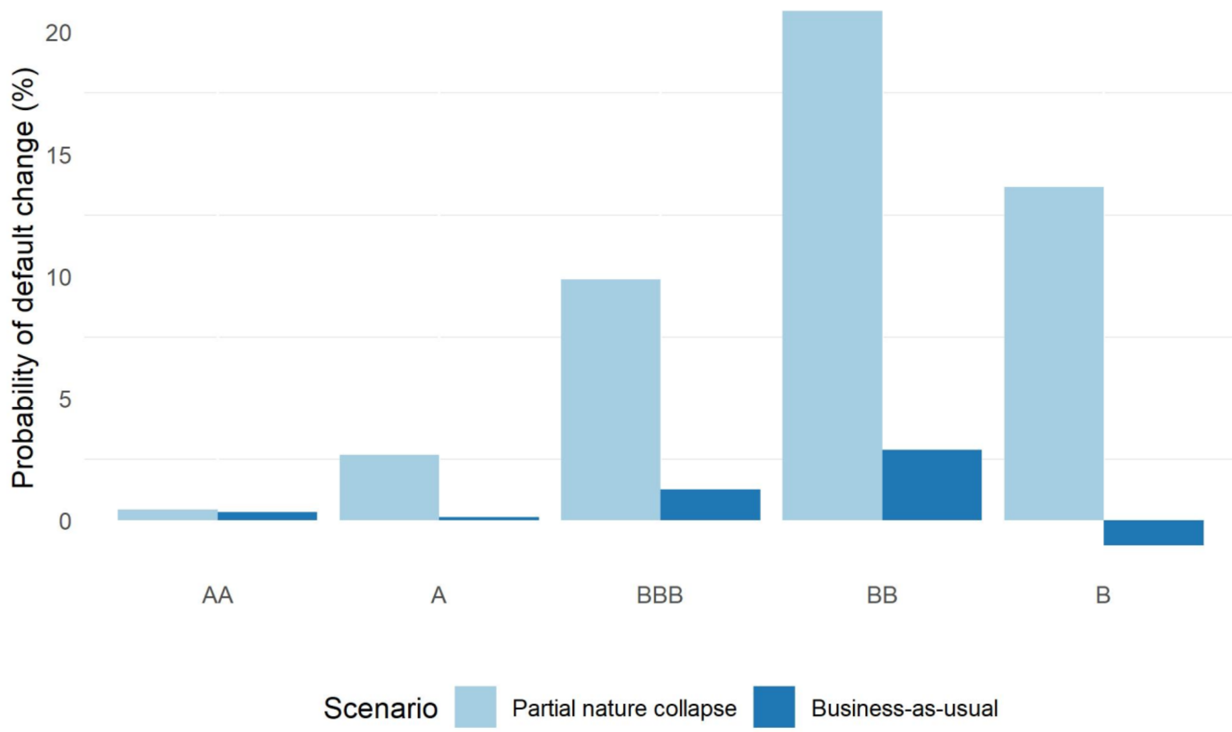
China and Malaysia would be hit the hardest, with rating downgrades by more than six notches in the partial collapse scenario. India, Bangladesh and Indonesia would face downgrades of approximately 4 notches. For China, the drop in creditworthiness would amount to additional interests on sovereign financing between $12-18 billion, while the 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.

Figure ES1: Rating changes due to partial nature collapse and BAU (gradual nature loss at current rates)



We also calculate the effect of nature loss on default probabilities (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 a *total* PD of over 50%.

Figure ES2: Average probability of default change by rating category (in % points, classified by 2020 estimated rating)



Our results have implications for stakeholders such as financial markets, financial intermediaries, general public, and sovereigns themselves.

- **Biodiversity and nature-related risks can have significant impacts** on sovereign creditworthiness, default probability, and the cost of capital.
- **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.
- **Credit Rating Agencies (CRAs) 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.
- **This is not just a story for bankers and finance ministries**. It is not only the bankers that lose out when damages affect investments 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 actions to reverse the trend in nature decline**. Economies that maintain or enhance natural capital could in principle see their creditworthiness improved, as depletions elsewhere makes their natural assets scarcer and more valuable.

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 5 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 ESG criteria to monitor and help mitigate nature-negative impacts. The newly formed Task Force 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 in Kunming, China for COP15 of the UN Convention on Biological Diversity (which will be continued in April/May 2022) 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

[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.

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 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 5 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). However, as the Covid-19 pandemic has demonstrated, 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 'spillover' 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 improved, 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 thus 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 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). Key challenges relate to the fact that environmental reporting definitions and methodologies are not standardised, especially along complex global supply chains (S&P Global 2021a). Whilst there is activity on behalf of ratings agencies, there remains considerable work to be done before nature is fully integrated into sovereign ratings.

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. However, it is 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 nature-related risks have emerged only more recently. 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 make 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 value added is 'moderately or highly dependent' on nature and its services to humanity (World Economic Forum 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. Given 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, alongside the systemic nature of ecological collapse, point to the possibility that nature loss could have significant macroeconomic implications.

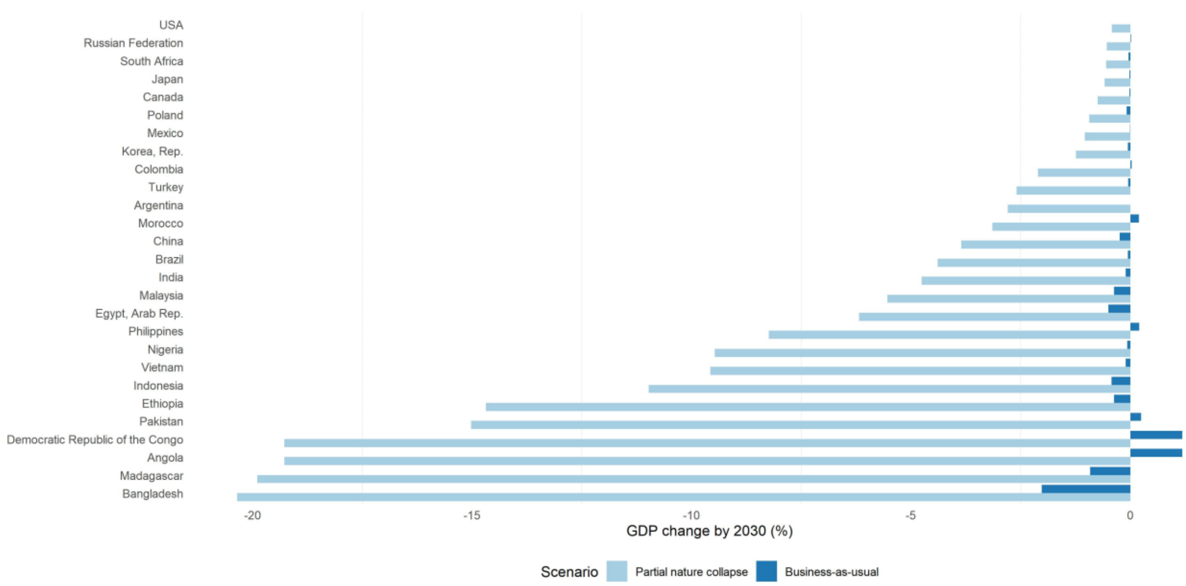
The 2021 World Bank report *Making the Economic Case for Nature* (Johnson et al. 2021) presents a first-of-its-kind attempt to identify the macroeconomic consequences of nature loss. Focussing on a collapse in the provision of select services including wild pollination, provision of food from marine 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 2021 and 2030. 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 to map 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 gets depleted 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). 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. (2020).

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 build 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.

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 tee. If we were trying to obtain a variable which explained whether a person would drink black coffee or fruit tee, 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. However, across the whole scale there are predictable patterns. 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 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 properties we may observe in other variables. The case is that often far more observations are found 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 element 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. However, there is 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 their performance variables is limited. In this case we use the GDP per capita and growth data from the World Bank and estimate their government performance variables based on the implied associations in the rest of the historical data. From this we also estimate their 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-adjusted credit ratings.

Once we obtain the biodiversity-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. There are even direct translations of this relationship,[3] whereby a downgrade by 1 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 loss and by the amount of outstanding debt they hold. 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

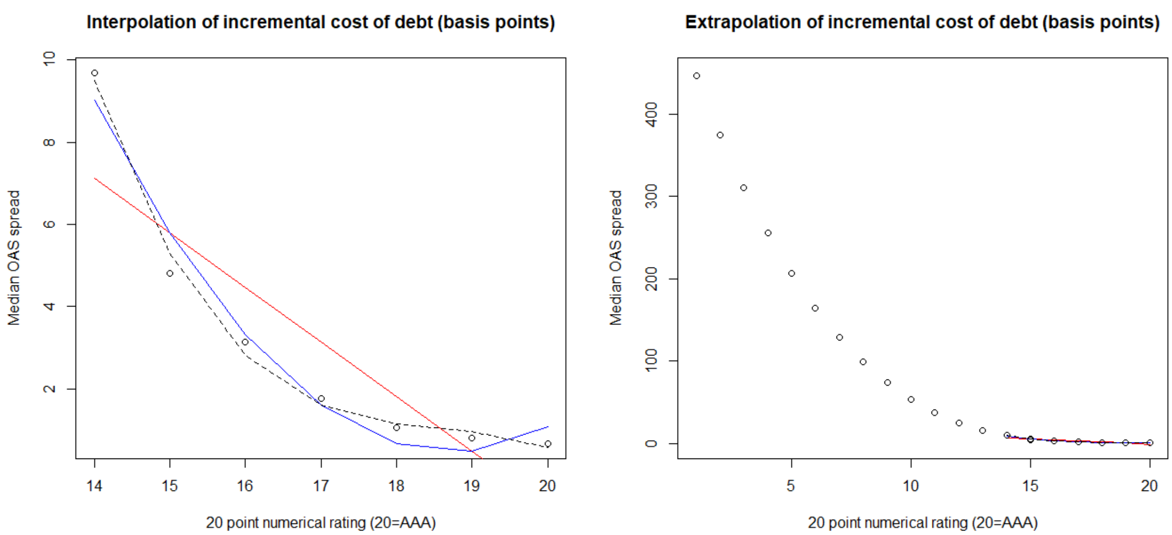
[2] Note that there is a fine line between investment (BBB-) and non-investment grade (BB+). For a conversion of alphabetical ratings into 20-notch scale see Appendix 1.

[3] 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.

(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



[4] As seen during previous sovereign debt crisis, sovereign downgrades can spillover 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.

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

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

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

5. Discussion of empirical 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.

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+, 4 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.

[8] 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.

[9] 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).

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

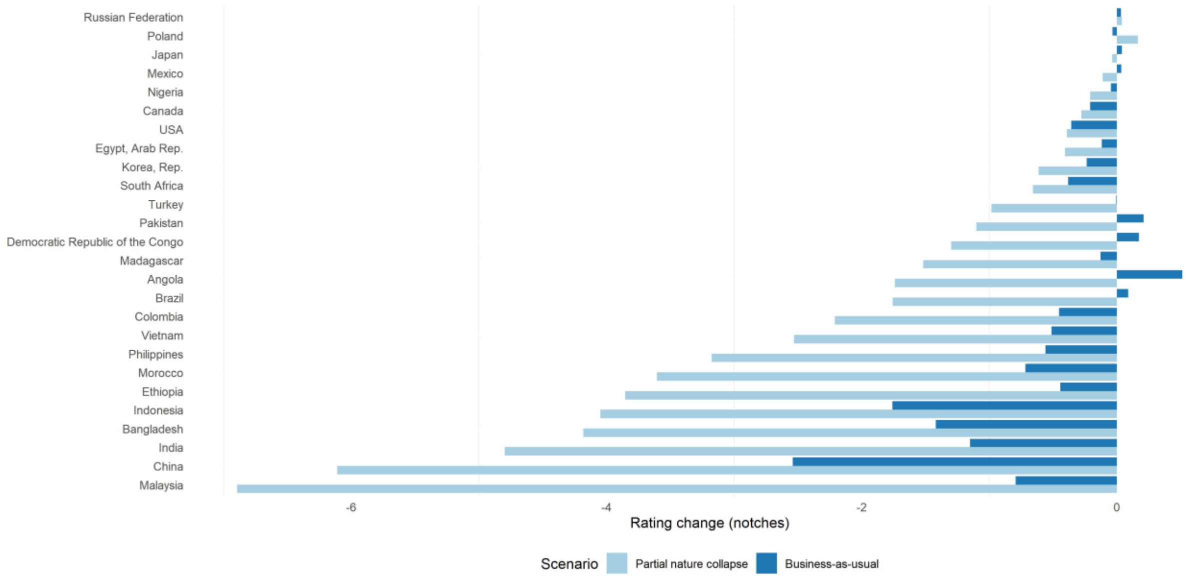
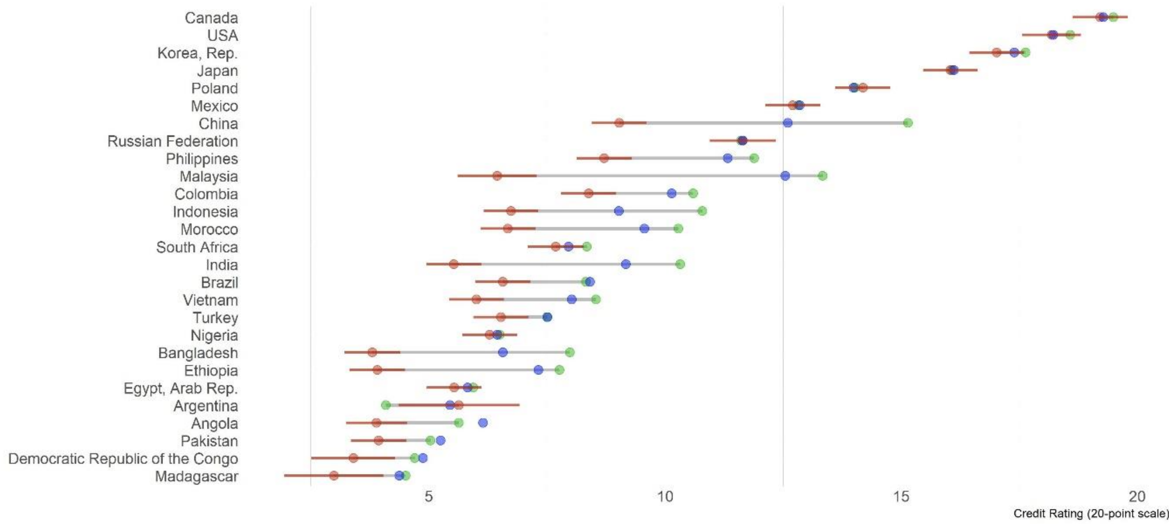


Figure 5 elaborates on the rating changes that would result from a partial ecosystem services collapse scenario and shows the pre- and post-shock sovereign ratings. The y-axis indicates the credit rating score (20-notch scale, with 20 being equivalent to AAA, and 10 or below being equivalent to a speculative 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 dependency on Biodiversity and Ecosystems Services (BES) tends to be greater for developing countries than for high-income economies (Retsa et al. 2020). However, it should be emphasised 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 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 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 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.

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

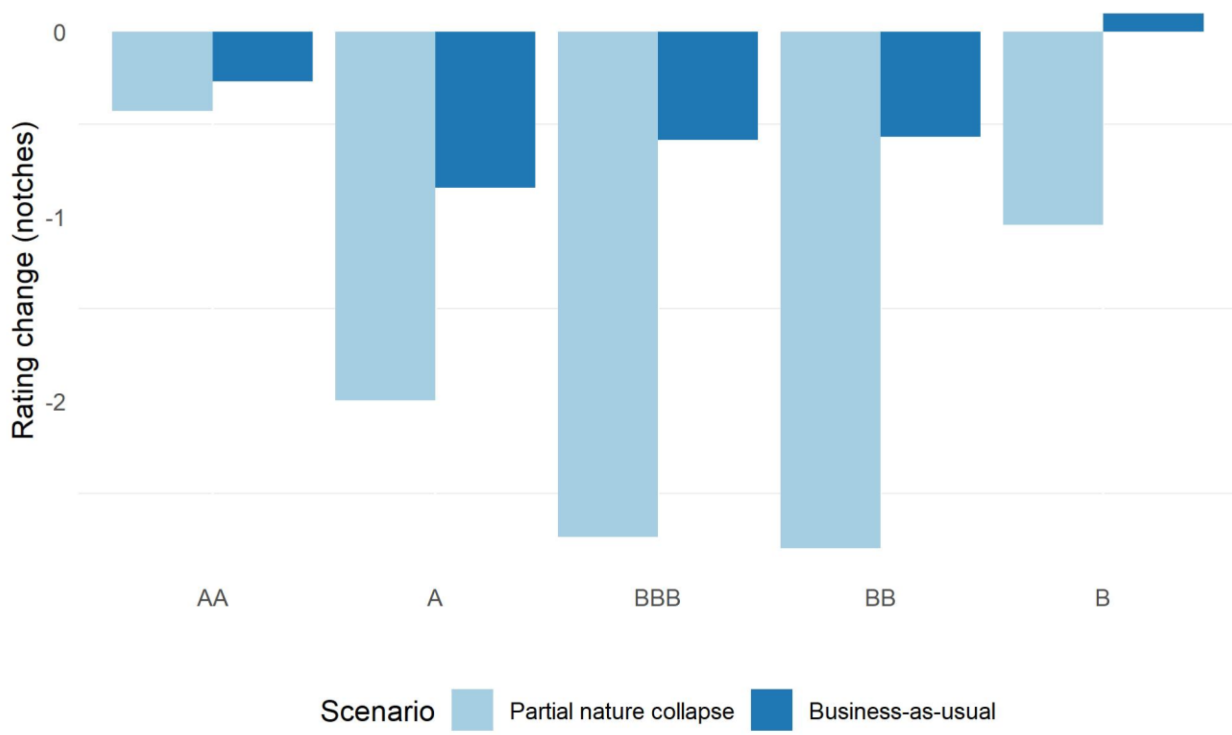


Nonetheless, our present set of results clearly suggests a greater impact on the creditworthiness of lower rated sovereigns. This finding is further corroborated in Figure 6, which shows the relationship between average rating changes and the estimated initial rating category in 2020. There is no discernible 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.

[10] 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.

[11] 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.

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



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 horizon. 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 monotonously 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 don't 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. 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

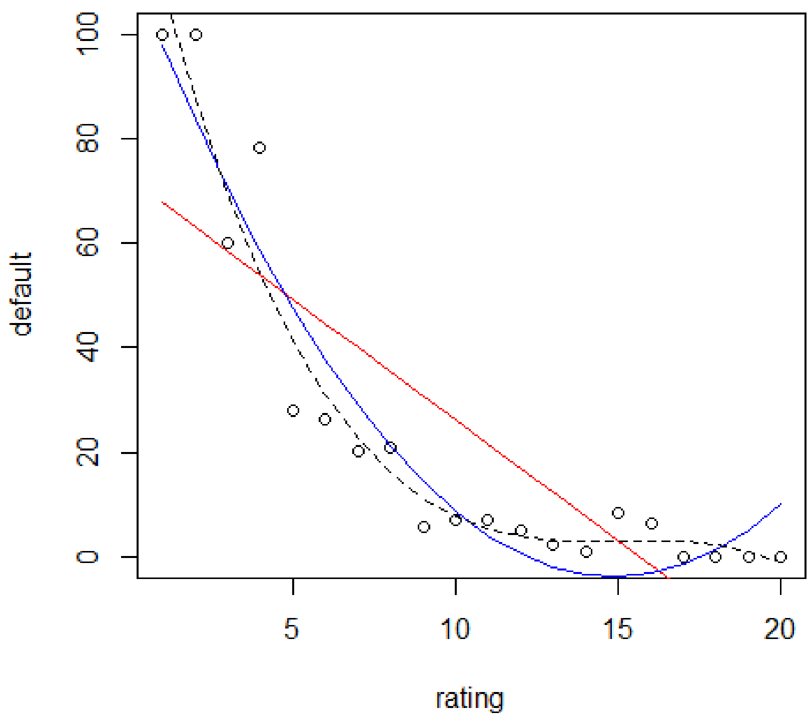


Figure 8 shows how the likelihood of default differs across rating categories. As expected, we can see the vulnerability of sovereigns rated in the speculative categories increasing further. The above-mentioned rating stickiness is reflected by a lesser effect of a partial collapse in ecosystem services 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)

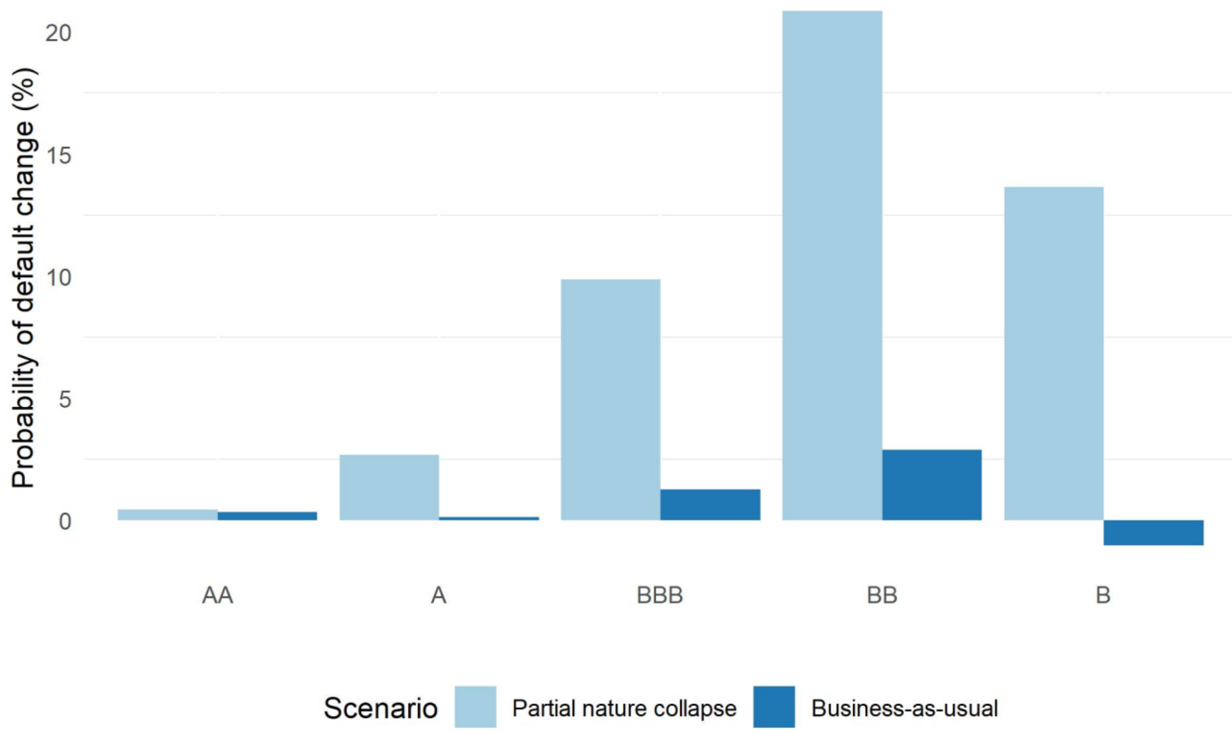


Figure 9 provides more PD detail on a country-by-country basis. There is no sovereign for which PD would increase under a partial ecosystem collapse as much as for Bangladesh (41%), with Ethiopia (38%) and India (29%) not far behind. Any PD increase above 10% should be considered substantial. 10% is 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)

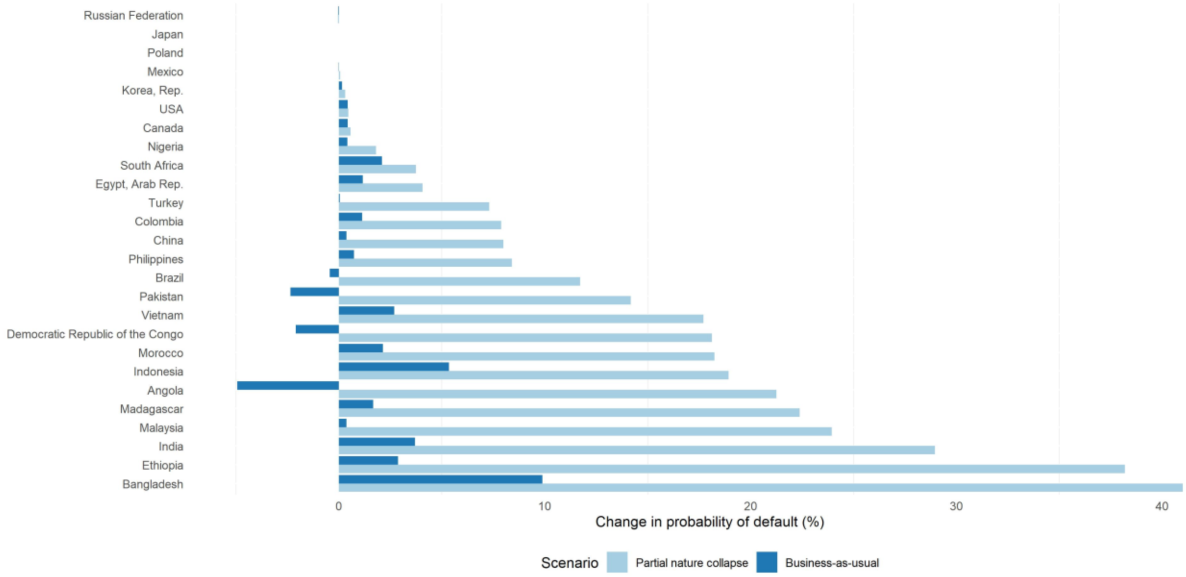


Figure 10: Probability of default without and with partial nature collapse (%)

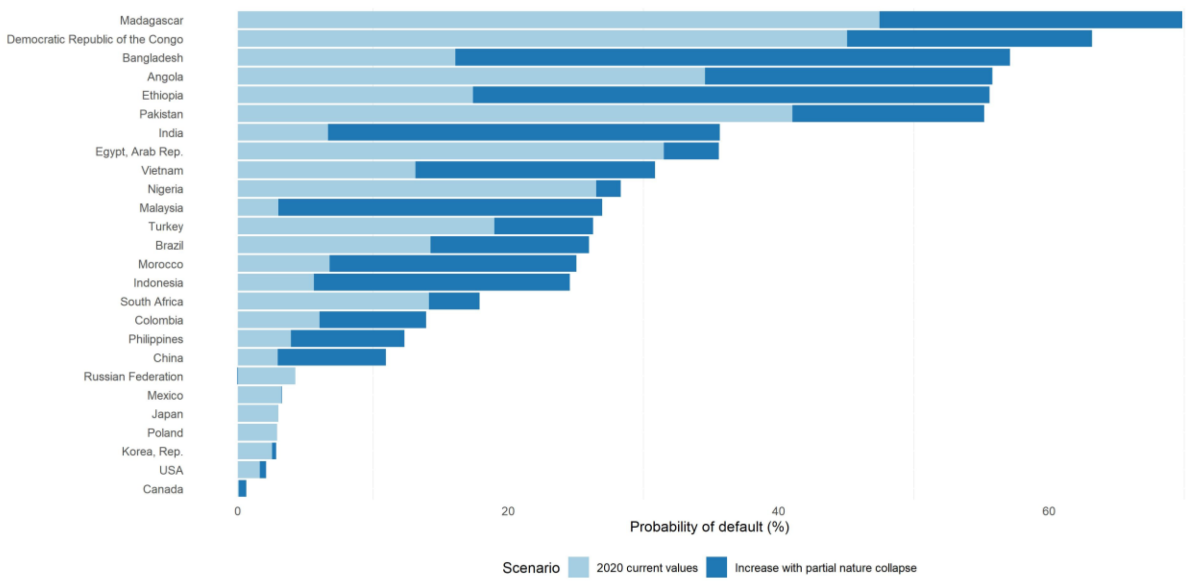
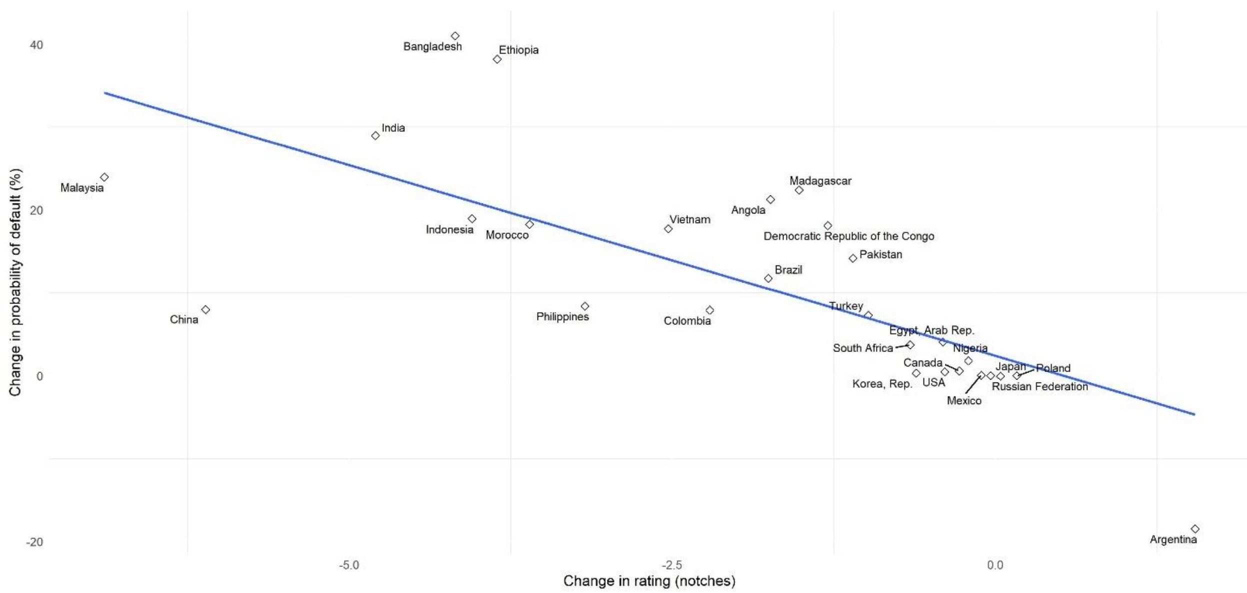


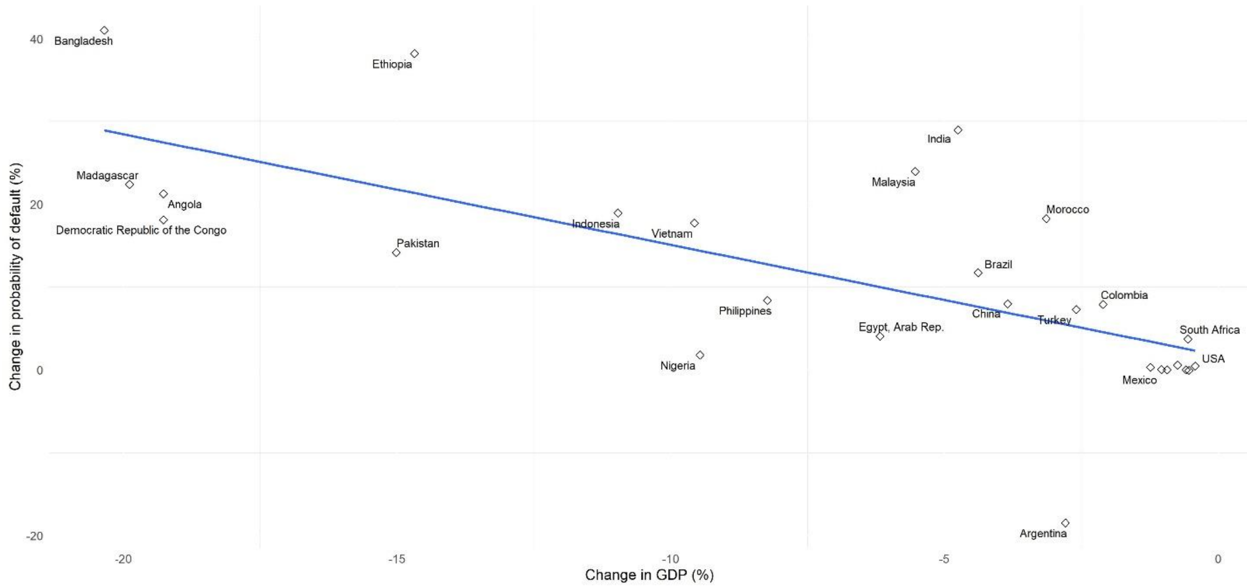
Figure 11 demonstrates that rating changes and PD changes are correlated, as one would expect them to be given that ratings are rankings of issuers with respect to agencies' opinions on PD. But while the correlation is there, it is not as tight as it would have been if ratings and PD expectations were 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, command 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



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 is 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 1 presents comparable results using two methods for all countries in our sample which are estimated to receive a downgrade larger than three notches. Table 2 presents the corresponding spillover 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)

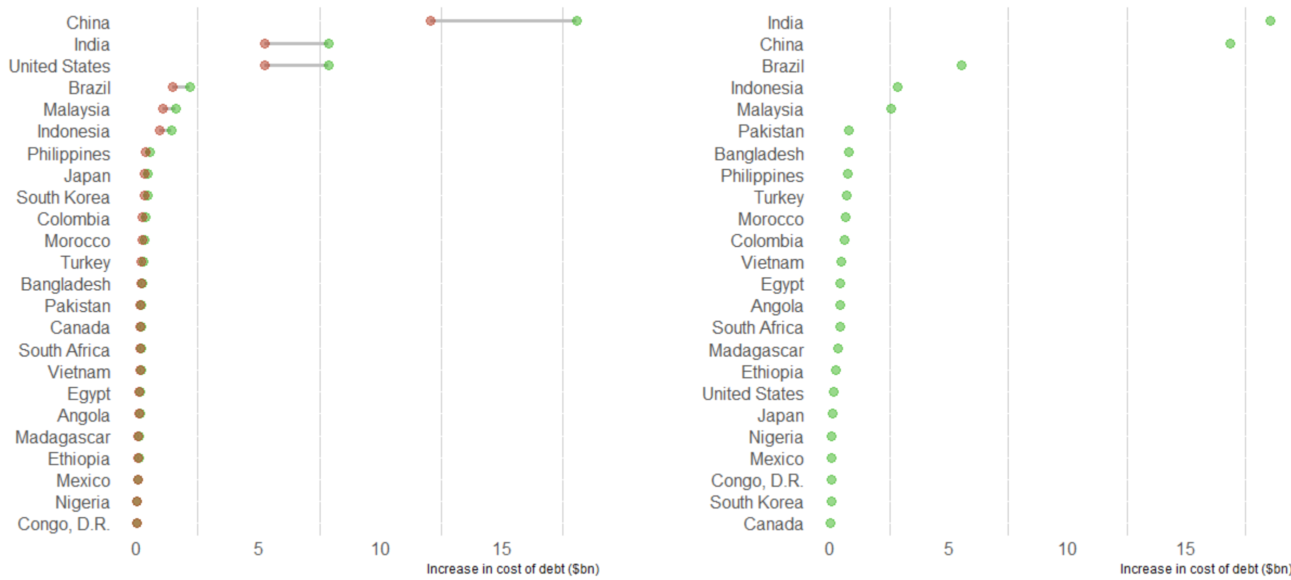


Table 1: Additional cost of borrowing for most affected sovereigns in the sample under the partial nature collapse scenario

			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-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 2: 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-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. Using a random forest model based on machine learning technique, 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. Using output loss data for these nature loss scenarios modelled by the World Bank for 26 countries, we show that the ratings of many sovereigns would be severely affected.

The estimated downgrades under the partial ecosystem services collapse scenario are much larger for most countries than 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 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.

For the partial ecosystem services collapse scenario, 15 out of 26 sovereigns (58% of the sample) would face a downgrade of one notch or more, but we see a wide variety of outcomes across the sample. About a third of the sovereigns (31% of the sample) would see their rating being 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 of ecosystem services scenario. India, Bangladesh and Indonesia would face downgrades by 4 notches. The downgrade prospect for these sovereigns are extremely significant. For instance, a nearly seven-notch downgrade would bring Malaysia's rating, currently rated A- by S&P, to B+, 4 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.

The report also estimates the probability of defaults (PD) resulting from nature loss. Under the partial ecosystem 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 by 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 default with a probability of over 50%.

Sovereign downgrades induced by partial nature loss would translate into higher costs of borrowing incurred by sovereigns and corporates. In the case of China, with a downgrade of approximately six notches in the partial ecosystem collapse scenario, the resulting additional costs of sovereign borrowing is estimated at between $12-18 billion, while the 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.

It should be emphasised that numerous high-income countries not included in our sample are among the countries globally with the highest share of fragile biodiversity and ecosystems. 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 fragile state 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 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.

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, 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.

Third, 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.[12] 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

[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).

sustainability/nature-linked bonds may also be achieved through credit enhancements provided by international financial organisations (Volz et al. 2021).

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Appendix

Appendix 1: 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		
D/SD	1	In default	

Notes: This table presents S&P alphabetical categories translated into 20-notch scale based on S&P's Global Rating Definitions available from: https://www.standardandpoors.com/en_US/web/guest/article/-/view/sourceId/504352