Network for Greening the Financial System

Technical document

Nature-related Financial Risks:

a Conceptual Framework to guide Action by Central Banks and Supervisors

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NGFS

Central Banks and Supervisors
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Foreword

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The twin crises of environmental degradation and climate change pose a significant threat to life on this planet. Economic activity depends on nature and society cannot function without the various services that nature provides. Consequently, the degradation of nature, but also actions aimed at preserving and restoring it, can have material macroeconomic, macroprudential, and microprudential consequences. Given these far-reaching implications for economies and financial systems, central banks and supervisors ought to consider these existential challenges.

Encouragingly, awareness of nature-related risks is growing within the financial system and beyond. At the end of 2022, nations around the world adopted the Kunming-Montréal Global Biodiversity Framework (GBF) at the 15th Conference of the Parties (COP15) to the Convention on Biological Diversity. The GBF aims to halt biodiversity loss and restore ecosystems by 2030 and for humans to live in harmony with nature by 2050. It assigns a prominent role to the financial sector, with explicit targets for disclosure and the alignment of financial flows.

Despite laudable progress, addressing these twin challenges remains a difficult task. The interaction between nature, climate and the economy is exceptionally complex. At the same time, the window of opportunity for an orderly transition is rapidly closing. The coming years are going to be critical for achieving both nature and climate goals. It is crucial that policies to address climate change and nature degradation are designed in conjunction with each other, because without the consideration for nature, actions to address climate change are bound to fall short. Despite the complexity, it is essential that central banks and supervisors start to assess nature degradation and its effects on the economy and the financial system, enhancing and harmonising our data, metrics and scenarios along the way.

In that spirit, we are proud to publish the final version of the NGFS Conceptual Framework on nature-related financial risks which seeks to guide policies and actions of central banks and supervisors. Following the release of its beta version in September 2023, it establishes a common understanding of nature-related risks to help central banks and supervisors navigate these complex challenges. To add colour to that understanding, the Conceptual Framework now also includes two illustrative cases that demonstrate the application of the risk assessment framework to freshwater and forest ecosystems.

The publication of the final Conceptual Framework is only the beginning. It marks the starting point of a continuous process to develop knowledge and experience in this field, being mindful of the fact that failing to act due to imperfect knowledge would almost certainly result in a 'too little, too late' scenario.

We genuinely appreciate the commitment and dedication of all Task Force members, who contributed to this document, as well as the valuable engagement of other stakeholders who provided input in the past year. Our special thanks go out to the team lead and the illustrative cases team in helping to complement and refine the beta version.

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1. Introduction

As is widely acknowledged, nature is fundamental to human well-being, a healthy planet, and economic prosperity. Without always realising it, humans depend on nature for food, medicine, energy, clean air and water, security from natural disasters, recreation, and cultural inspiration (among many other things). But human demands have exceeded the planet's ability to provide such services, resulting in a degradation of nature and its diversity at unprecedented rates[1]. For example, monitored wildlife populations have declined by an average of 69% since 1970[2], and the global rate of species extinction is tens to hundreds of times higher than it has been over the past 10 million years[3]. Furthermore, six of the nine boundaries that maintain the resilience and stability of the Earth have been exceeded[4]. This continued degradation poses a threat to well-being[5] and, more fundamentally, to the planet's habitability[6]. In response, the Kunming-Montreal Global Biodiversity Framework ("GBF") was adopted in 2022 with a new set of goals and targets to halt and reverse biodiversity loss. Its overarching vision is for humans to live in harmony with nature by 2050. 23 targets are set for 2030 to achieve this vision[7].

The degradation of nature, and actions aimed at preserving and restoring it, will affect our economies and financial systems. To illustrate, the GBF requires, among other things, the alignment of all financial flows by 2030 with its targets and goals[8]. Based on the findings of a joint NGFS-INSPIRE study group, the NGFS has acknowledged that nature-related financial risks could therefore have significant macroeconomic implications, and that failure to account for, mitigate, and adapt to these implications is a source of risks relevant for financial stability[9]. To effectively address these risks, the NGFS has set up a task force on Biodiversity Loss and Nature-related Risks ("Task Force"). The objective of the Task Force is to help **mainstream the consideration of nature-related financial risks across the NGFS**. As part of this effort, the Task Force is mandated to **develop a conceptual framework on nature-related financial risks to guide action by central banks and supervisors**[10].

This document contains the **NGFS Framework for nature-related financial risks** (the "Framework"). The Framework seeks to create a common science-based understanding of, and language for, these nature-related financial risks among NGFS members. Its aim is to provide greater clarity on the meaning of key concepts and the way these interrelate. In doing so, the Framework adopts an integrated approach. This means that climate-related financial risks are strongly interconnected with the broader environmental-related financial risks, and therefore considered within the scope of nature-related financial risks (without prejudice to the relevance of the NGFS' work on climate)[11].

The Framework also contains a principle-based risk assessment framework to help operationalise the conceptual understanding of nature-related financial risks. In this way, the Framework helps central banks and supervisors to identify and assess material nature-related financial risks. Where relevant, it may also help to develop policies and actions in respect of those material risks while taking into consideration the relevant jurisdictional context and mandate. Considering that purpose, and without being prescriptive, the Framework draws attention

1 *Kunming-Montreal Global biodiversity framework (CBD/COP/DEC/15/4)*, December 2022.

2 *Living Planet Report 2022 – Building a nature-positive society*, World Wildlife Fund ("WWF"), 2022.

3 *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*, The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services ("IPBES"), 2019.

4 Richardson, J. , *et al.* (2023) *Earth beyond six of nine Planetary Boundaries*, Science Advances.

5 *Kunming-Montreal Global biodiversity framework (CBD/COP/DEC/15/4)*, December 2022.

6 Final Report, NGFS-INSPIRE Study Group, March 2022.

7 *Kunming-Montreal Global biodiversity framework (CBD/COP/DEC/15/4)*, December 2022. The GBF succeeds the UN Strategic Plan for Biodiversity 2011-2020 that included the Aichi Biodiversity Targets (none of which were fully met).

8 Ibid. See Target 14.

9 Statement on Nature-Related Financial Risks, NGFS, 24 March 2022.

10 Task force "Biodiversity Loss and Nature-related Risks" Mandate April 2022 – April 2024, NGFS, 2022.

11 Consequently, nature-related financial risks cover both "climate-related risks" and "environmental-related risks" as previously defined in: A call for action – Climate change as a source of financial risk, NGFS, 2019 (p. 11).

to the considerations that are most likely to be relevant from a microprudential, macroprudential and/or macroeconomic perspective (and which may therefore affect financial stability or price stability). At the same time, it is acknowledged that other facets of nature and its degradation – such as effects on well-being or nature-related economic opportunities – could merit consideration outside the context of this Framework. **Two illustrative cases are included in the Framework to provide colour to the potential application of the risk assessment framework.** By applying the Framework to the specific examples of the Amazon and Colorado River Basin, the illustrative cases demonstrate in a largely qualitative manner how the different phases and guiding questions in the Framework can be navigated.

The Framework is only a starting point for analysis and action. Its content is not meant to be comprehensive or set in stone. As knowledge and experience develops, this Framework may be refined and supplemented over time.

2. Understanding nature-related financial risks

To mainstream the consideration of nature-related financial risks beyond climate across the NGFS, it is important to start with a shared understanding of the meaning of, and language for, these risks. This chapter defines **nature-related financial risks and related concepts that are needed for a high-level understanding of these risks.** In doing so, it draws on scientific literature including reports by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services ("IPBES"). Full definitions for the key concepts (highlighted in **bold**), and references to their sources, can be found in Annex 1.

The natural world

As a starting point, it is necessary to reflect briefly on the meaning of **nature.** Nature itself is challenging to define, and its interpretation depends strongly on the context in which it is used[12]. In the IPBES Conceptual Framework, it has been described as: "The natural world with an emphasis on the diversity of living organisms and their interactions among themselves and with their environment[13]." For this Framework, the key consideration is that the term 'nature' captures both the biotic (living) and abiotic (non-living) elements on our planet, including biodiversity but also climate. Some of these elements, such as natural resources (plants, animals, air, water, soils, minerals etc.), are sometimes also referred to as natural capital[14].

The living and non-living elements of nature combine in **ecosystems,** which provide a flow of benefits described as **ecosystem services** (or nature's contribution to people[15]). Ecosystem services provide society with tangible goods (e.g., timber or food); the regulation of natural processes (e.g., carbon sequestration, surface temperature cooling, watershed protection and erosion control); supporting services (e.g., nutrient cycling and soil formation); and cultural services (e.g., recreation and tourism). See Annex 2 for more details on different types of ecosystems and ecosystem services.

The ability of nature to provide these ecosystem services depends on biodiversity[16]. **Biodiversity** relates to the living elements of nature, and refers specifically to variability among living organisms which includes the diversity within species, between species and of ecosystems. There is strong scientific evidence that this diversity is critical for the resilience, adaptability and productivity of ecosystems[17]. Biodiversity should therefore be understood as an integral characteristic of healthy ecosystems.

Degradation of nature

Human society and the global economy cannot exist without ecosystem services. Yet, human activities have driven an unprecedented degradation of nature and its biodiversity that threatens the continued provision of the very ecosystem services on which humans depend (14 of the 18 global ecosystems have declined since 1970[18]).

12 Final Report, NGFS-INSPIRE Study Group, March 2022.

13 Díaz, S., *et al.* (2015) *The IPBES Conceptual Framework – connecting nature and people.* This definition is also referenced by the Taskforce on Nature-related Financial Disclosures ("TNFD") to describe nature.

14 Although not a key concept to understand or act on nature-related financial risk, the term is referenced in the Framework to place it into context. This terminology focuses especially on nature's contributions to human economic activity, emphasising that nature is a stock of assets that provide a flow of benefits to people. For completeness, a full definition is provided in the glossary.

15 See Díaz, S., *et al.* (2018) *Assessing nature's contributions to people,* Science.

16 Final Report, NGFS-INSPIRE Study Group, March 2022. See also Mace, G.M., Norris, K. & Fitter, A.H. (2012). *Biodiversity and ecosystem services: a multilayered relationship*. Trends in Ecology & Evolution.

17 See for example The Economics of Biodiversity: The Dasgupta Review, February 2021. The treatment of the link between biodiversity and ecosystem functioning in the Dasgupta review is taken from the following major reviews: Hooper, D.U., *et al.* (2005) *Effects of Biodiversity on Ecosystem Functioning: a Consensus of Current Knowledge*. Ecological Monographs; Cardinale, B. J., *et al.* (2012) *Biodiversity Loss and its Impact on Humanity*. Nature; Tilman, D., Isbell, F. & Cowles, J. M. (2014) *Biodiversity and Ecosystem Functioning*. Annual Review of Ecology, Evolution, and Systematics.

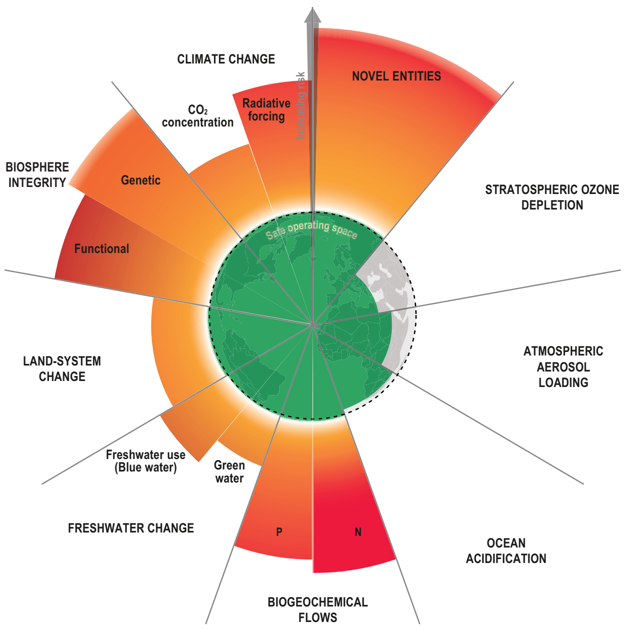
18 *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services,* IPBES, 2019.

Five main drivers of nature degradation have been identified, starting with the most impactful drivers at a global level: (i) changes in land and sea-use; (ii) over-exploitation of natural resources (i.e., extraction of living and non-living materials); (iii) climate change (iv) pollution; and (v) invasive alien species[19].

The degradation of nature can be acute (i.e. shocks such as oil spills, forest fires or pests affecting a harvest) and/or chronic (i.e. gradual changes such as pollution stemming from pesticide use or climate change)[20]. When that degradation occurs, and at what scale, is often difficult to measure or predict. Among other things, this is because changes in the natural environment are not linear and characterised instead by compounding effects and 'tipping points'[21]. These tipping points are abrupt and possibly irreversible shifts between alternative ecosystem states[22]. The likelihood of reaching tipping points increases when 'planetary boundaries' are crossed. Planetary boundaries are a concept that indicate limits of the Earth's 'safe operating space'. Leaving the safe operating space increases the risk that large-scale abrupt or irreversible environmental changes occur[23]. Evidence suggests that, because of human changes and pressures, several of these boundaries have already been exceeded (see figure 1)[24]. To illustrate, climate change and human alterations to water bodies and land have led to global-scale river flow changes and shifts in water vapour flows[25]. Such shifts in the hydrological system can be permanent and occur abruptly.

The crossing of planetary boundaries could be therefore interpreted as an indication of the Earth's susceptibility to physical hazards or shocks[26]. For example, in the case of climate, multiple tipping points could already be triggered when 1.5 °C global warming is exceeded (e.g. collapse of ice sheets, coral reef die-off and permafrost thaw)[27]. Crossed boundaries could also indicate domains where action might be expected to bring the Earth back to its safe operating space and reduce the risk of reaching tipping points (e.g., in respect of freshwater, novel entities such as plastics or nitrogen emissions). The latter is in recognition of the fact that, driven by various motives and values[28], nature degradation has triggered action to protect, restore, and/or reduce negative impacts on nature. Such action can manifest as changes in regulation and policy, legal precedent, technology, or investor sentiment and consumer preferences.

Figure 1 **Planetary boundaries**



Source: Azote for Stockholm Resilience Centre, based on analysis in Richardson et al. *2023).*

19 Described as direct drivers of change in nature in the *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services,* IPBES, 2019.

20 Final Report, NGFS-INSPIRE Study Group, March 2022.

21 Kedward, K., Ryan-Collins, J., & Chenet, H. (2022) *Biodiversity loss and climate change interactions: financial stability implications for central banks and financial supervisors*. Climate Policy.; Lenton, T. M. (2013) *Environmental tipping points.* Annual Review of Environment and Resources.

22 Dakos, V., *et al.* (2019) *Ecosystem tipping points in an evolving world*. Nature, Ecology and Evolution. Description referenced in Final Report, NGFS-INSPIRE Study Group, March 2022.

23 Rockström, J., *et al.* (2009) *Planetary boundaries: exploring the safe operating space for humanity*. Ecology and Society.

24 Richardson, J., *et al.* (2023) *Earth beyond six of nine Planetary Boundaries*, Science Advances.

25 See *e.g.* Porkka, M. (2024*) Notable shifts beyond pre-industrial streamflow and soil moisture conditions transgress the planetary boundary for freshwater change*. Nature Water.

26 In this context, it should be noted that the global planetary boundaries only provide a coarse indication and may not always reflect the transgression of these boundaries at a more local level.

27 Armstrong McKay, D. I., *et al.* (2022) *Exceeding 1.5 C global warming could trigger multiple climate tipping points*, Science.

28 The Framework emphasises the relevance of nature for economic activity, but a broader spectrum of values and ways of relating to nature may motivate actions to restore nature. See also *Methodological Assessment Report on the Diverse Values and Valuation of Nature,* IPBES, 2022.

Planetary boundaries, ecosystem services and scenarios

Planetary boundaries and ecosystem services are also key concepts in the NGFS Recommendations toward the development of scenarios for assessing nature-related economic and financial risks ("NGFS Technical Document on Nature Scenarios"). An understanding of these concepts may therefore help to assess nature-related risks on a forward-looking basis. Specifically, planetary boundaries and ecosystems services play an important role in the development of nature scenario narratives (i.e., storylines that describe how the world could evolve in the future as a result of nature degradation or actions to address it).

Planetary boundaries indicate, on a global level, the distance between the current and safe operating space for nine natural processes that regulate the Earth system (e.g., climate change, changes in the freshwater system or the introduction of novel entities such as microplastics). This global concept is relatively coarse, but when scaled down to a national level, it becomes possible to identify which ecosystems are more degraded than others and therefore more likely to collapse. This is the general idea behind the ESGAP-SESi approach for narrative development as presented in the NGFS Technical Document on Nature Scenarios. Using 21 indicators of ecosystem health (e.g., outdoor air pollution, soil erosion rate, fish resources), ESGAP-SESi provides an aggregate measure to determine the distance between current state and a "healthy" operating state for different ecosystems. This distance can be used as a proxy to determine the potential occurrence of physical hazards. In other words, the closer a country is to crossing thresholds for these indicators, the less resilient the relevant ecosystem is and the more likely it becomes that physical hazards occur.

The state of these ecosystems matters because it affects the ecosystem services provided by those ecosystems on which economic actors depend. One ecosystem can provide a number of different ecosystem services. These services are typically categorised as follows (see also Annex 2):

- Provisioning services: e.g. food, raw materials like timber, fresh water;
- Regulating services: e.g. carbon sequestration and erosion control;
- Cultural services: e.g. recreation and tourism; and
- Support services: e.g. nutrient cycling and soil formation.

Ecosystem services also play a central role in the other approach to narrative development highlighted in the NGFS Technical Document on Nature Scenarios: the INCAF-Oxford approach. This approach focuses on potential hazards and maps the relationship between those hazards (i.e. shocks such as a grain crop pest) the particular ecosystem services in a country or region (e.g. backwards to the disrupted ecosystem service 'pest control') and forwards to the effects it has on the food provisioning services and sectors that depend on it). Relevant hazards can be selected from a initial set of over fifty hazards based on the vulnerability of the relevant county or region to those hazards.

Physical and transition risks

Like climate-related risks[29], nature-related financial risks can thus be categorised as **physical risks** (stemming from the degradation of nature and loss of ecosystem services) or **transition risks** (stemming from a misalignment of economic actors with actions aimed at protecting, restoring, and/or reducing negative impacts on nature). With regard to transition risk, the misalignment often results from the negative impacts that economic actors have on nature. But, it is important to note that risks could also arise from activities originally aimed at restoring nature that no longer align with, for example, revised best practices, new technologies or updated regulatory requirements.

Consistent with the NGFS approach for climate change, litigation risk is considered in this Framework as a subset of both physical and transition risks[30]. Litigation risks can arise from a variety of factors, including liability claims, policy and regulatory changes, and misconduct. In the case of physical risks, litigation may be brought against a company, state or public entity that is alleged to be responsible for causing harm to ecosystems (which, given the often more localised impacts on nature, may be easier to attribute to a particular company). Equally, as part of transition risks, litigation risk may arise when businesses fail to adapt to new regulations and face legal consequences[31]. Mismanagement of nature and climate risks can also lead to legal action, including cases against directors who intentionally mislead investors[32]. Key emerging trends related to nature-related litigation are explored in greater detail in an NGFS Report on nature-related litigation[33] that also explores the potential impact of nature-related litigation for central banks, supervisors and the financial system.

Physical and transition risks can affect the economy at micro, sectoral/regional and macro levels (including as effects on price stability). These include effects resulting from permanent changes in nature that have already occurred, as well as effects from potential future changes. Those economic risks can subsequently translate into financial risks that adversely affect individual financial institutions or financial systems as a whole. In this context, it is important to note that nature-related financial risks are also endogenous: the impacts that economic and financial actors have on nature affect the financial risks these actors need to manage. For instance, through the economic activities that they finance, financial institutions can contribute to the build-up of nature-related financial risks (or contribute to the reduction of such risks)[34]. Figure 2 provides an overview of the relevant transmission channels.

In light of the above, **nature-related financial risks are defined as follows for the purposes of this Framework:**

Nature-related financial risks refer to the risks of negative effects on economies, individual financial institutions and financial system that result from:

i. *the degradation of nature, including its biodiversity, and the loss of ecosystem services that flow from it (i.e., physical risks); or*
ii. *the misalignment of economic actors with actions aimed at protecting, restoring, and/or reducing negative impacts on nature (i.e., transition risks).*

29 A call for action – Climate change as a source of financial risk, NGFS, 2019.

30 Climate-related litigation: Raising awareness about a growing source of risk, NGFS, 2021. It is recognised that other frameworks may adopt a different approach, for instance viewing litigation risk as a separate risk category.

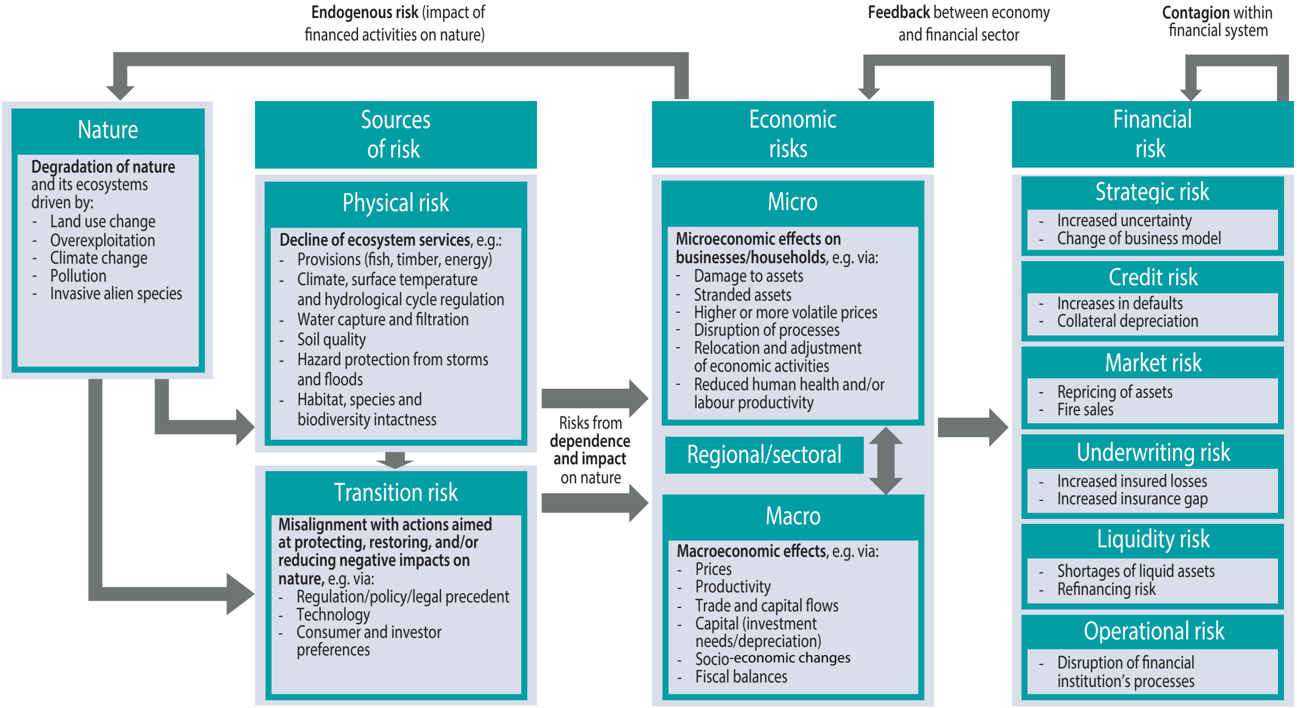
31 Ibid. The approach for climate-related litigation could be extended to broader nature-related litigation risks.

32 *Biodiversity Risk: Legal Implications for Companies and their Directors,* Commonwealth Climate and Law Initiative, December 2020.

33 Nature-related litigation: emerging trends and lessons learned from climate-related litigation, NGFS, 2024.

34 Final Report, NGFS-INSPIRE Study Group, March 2022.

Figure 2 **Transmission channels**



Sources: Adapted from Svartzman, R. et al. *(2021) A "Silent Spring" for the Financial System ? Exploring Biodiversity- Related Financial Risks in France.*

3. Assessing nature-related financial risks

Based on the understanding of nature-related financial risks, this chapter offers a **framework to help central banks and supervisors identify and assess those nature-related financial risks that are material for their economy and financial system.** Its aim is to help operationalise the conceptual understanding of nature-related financial risks. At the same time, it should be noted that analytical methodologies and risk management practices are still being developed[35]. Furthermore, actions taken will depend on the context in each jurisdiction and organisation, including differences in mandates. Considering this need for flexibility, the current Framework adopts a principle-based approach (as opposed to providing detailed, prescriptive guidance).

The principle-based risk assessment framework consists of three phases[36]. A few guiding questions are provided at the end of each phase to draw attention to key elements that central banks and supervisors could consider as part of their risk identification and assessment. For an overview, see Annex 3.

Phase 1: Identify sources of physical and transition risk

As a first step, central banks and supervisors could identify the sources of risk that are potentially material from a microprudential, macroprudential and/or macroeconomic risk perspective[37]. This section provides a **high-level approach to the identification and prioritisation of sources of physical and transition risk based on exposures.** As part of the approach, particular attention is drawn to the relevance of forward-looking, location-specific and systemic dimensions. Further details are also provided on the interlinkages between climate and the broader dimensions of nature. The latter is intended to help supplement existing climate-related efforts and enable a more integrated approach to risk management.

Exposures to impacts and dependencies

Analysing the exposures to dependencies on nature and/or impacts of economic activity on nature can be a first step to identify sources of physical and transition risks (both as defined in chapter 2). Examples of such exposure analyses include the physical risk analyses based on the ENCORE database as conducted in the Netherlands, France, Brazil, Malaysia, Mexico, the euro area and other jurisdictions[38]. The outcomes of the initial exposure analysis can help to identify sectors and/or ecosystems services that are more likely to be sources of material risk (and could therefore be prioritised as a starting point for the assessment of risk in phases 2 and 3).

35 For instance, the NGFS Technical Document on Nature Scenarios provides several recommendations to advance the development of scenarios to assess economic and financial risk. See Recommendations toward the development of scenarios for assessing nature-related economic and financial risks, NGFS, December 2023.

36 Adapted from the approach for forward-looking risks assessments in the Final Report, NGFS-INSPIRE Study Group, March 2022.

37 This phase shares similarities with the 'Locate' and 'Evaluate' phases in the TNFD LEAP approach.

38 For a more detailed description and references to the risk assessments, see the Final Report, NGFS-INSPIRE Study Group, March 2022. For more recent work, see also: Martinez-Jaramillo, S., *et al.* (2023) *Dependencies and impacts of the Mexican banking sector on ecosystem services;* Boldrini S., *et al.* (2023) *Living in a world of disappearing nature: physical risk and implications for financial stability,* European Central Bank ("ECB"); Ceglar, *et al.* (2023) *The impact of the euro area economy and banks on biodiversity,* ECB; Assessing Nature-Related Financial Risks: The Case of Lithuania, Bank of Lithuania, December 2023; The Nature of Finance – Assessing the nature-related risks and opportunities for the Irish Financial Sector; KPMG on behalf of Ireland's International Sustainable Finance Centre of Excellence; December 2023; Bayangos, V. B., *et al.* (2023) The Impact of Biodiversity Loss on the Philippine Banking System: A Preliminary Analysis; *Nikuradze, E. & Tvalodze, S. (2023)* Biodiversity-related Financial Risks – why it matters and how can we measure them?, *National Bank of Georgia.*

- **Sector-based prioritisation:** Identify key economic activities or sectors that are more likely to be at risk based on the level of their dependencies/impacts on nature (including via value chains) as well as their relevance to the economy, individual financial institutions or financial sector (e.g. the value of the exposure compared to the total value of exposures analysed). To illustrate, economic activities with high impacts and dependencies on nature occur in sectors that include agriculture, aquaculture and fisheries, forestry, metals and mining, transport, energy and utilities, textiles and apparel, chemicals and pharmaceuticals, construction and infrastructure[39]; and/or
- **Ecosystem-based prioritisation:** Identify key ecosystem services on which economic activities depend, thereby considering the ecosystems from which they originate and the vulnerability of those ecosystems given negative impacts on them (see also Annex 2 for more detail on the different ecosystems and ecosystem services)[40].

The above analysis may only yield a partial picture of potential sources of risk due to remaining uncertainties and data constraints. Other indications of potential risks (both quantitative and qualitative) may therefore need to be considered. The sections below seek to complement the initial exposure analysis by drawing attention to the relevance of forward-looking, location-specific and systemic dimensions.

Forward-looking dimension

The initial analysis as described above provides a static snapshot of current exposures. This could be supplemented with scenario analyses to explore exposures – and therefore sources of physical and transition risks – on a forward-looking basis[41]. For physical risks, the source of risk can be the extrapolation of a trend or hypothetical shock in which one or more ecosystems or ecosystem services degrade or collapse[42]. For transition risks, existing and announced nature-related policies on a global, regional and/or national level could provide a starting point to develop scenarios (for example the GBF, which defines 2030 targets on, among other things, protecting 30% of land and water[43] or the reduction of harmful subsidies[44])[45]. It is relevant to understand and consider the expected time horizon for these scenarios (i.e., will they materialise in the short, medium or long term).

Lessons can be learnt from previous work on climate scenarios when developing such forward-looking exposure analyses (and, if feasible, forward-looking risk assessments in phases 2 and 3). But nature presents a number of open questions and unique challenges that must be carefully accounted for[46]. To assist central banks and supervisors with forward-looking analyses, the Task Force has produced a Technical Document on Nature Scenarios. The documents identifies a number of challenges that must be accounted for when developing nature scenarios. At the same time,

39 Based on sectors highlighted in Sector Guidance – Additional guidance for financial institutions (v. 1.0*)*, TNFD, September 2023, WWF Risk Filter – Overview – dependencies and impacts, WWF; *The Biodiversity Crisis Is a Business Crisis,* Boston Consulting Group ("BCG"), 2021; *Nature Risk Rising: Why the Crisis Engulfing Nature Matters for Business and the Economy*, World Economic Forum ("WEF"), 2020.

40 For examples, see also Guidance on biomes *(v. 1.0)*, TNFD, September 2023.

41 And, in phases 2 and 3, assess risk on a forward looking basis (e.g. via a stress test).

42 See for instance: *An Exploration of Nature-Related Financial Risks in Malaysia,* World Bank Group and Bank Negara Malaysia*, 2022;* Prodani, J., *et al.* (2023) The economic and financial stability repercussions of nature degradation for the Netherlands: Exploring scenarios with transition shocks*,* DNB. For an assessment of economic risk (i.e. phase 2), see also: Johnson, J. A., *et al.* (2021) *The Economic Case for Nature: A Global Earth-Economy Model to Assess Development Policy Pathways.*

43 See e.g. *Indebted to nature: Exploring biodiversity risks for the Dutch financial sector*, De Nederlandsche Bank (DNB) and The Netherlands Environmental Assessment Agency (PBL), 2020.

44 More information on the targets is at www.cbd.int/gbf/targets/. For a discussion, see also COP15 marked a decisive moment for central banks and supervisors to address nature risks in the Anthropocene, Grantham Research Institute on Climate Change and the Environment, January 2023.

45 The NGFS Technical Document on Nature Scenarios also contains a review of various transition policies and trends to help identify plausible transition shocks.

46 For further details: Final Report, NGFS-INSPIRE Study Group, March 2022. See also The TNFD's proposed approach to scenario analysis, TNFD, November 2022.

it offers approaches that central banks and supervisors can use to better understand the nature-related financial risks on a forward-looking basis. This includes suggestions for the use of input-output tables and models, biophysical models, and nature-economy models. First examples of such forward-looking risks assessments include the two case studies incorporated in the Technical Document on Nature Scenarios, an explorative scenario study published by DNB and an assessment of nature-related financial risks for the UK[47].

Scale: local and systemic dimensions

Nature is spatially explicit. In other words, nature is distinct for each location and differs across locations. This is also the case for the impacts and dependencies on it. For example, activities may rely on ecosystem services provided by local ecosystems, or negative impacts may occur in ecosystems that are already fragile. Therefore efforts to identify and prioritise risks should take into account the geographical location of impacts and dependencies[48].

At the same time, local impacts and dependencies can have systemic implications due to spill-over and feedback effects. In addition to any direct effects of impacts and dependencies on a limited number of individual parts or actors in the system (such as a particular ecosystem, household, company or financial institution), risk may therefore also originate from more complex and indirect causal chains[49]. This 'local-global trade-off' presents challenges in coordinating between the micro-level scale of analysis (location-specific) and the macro-level global scale (systemic effects)[50].

Considering these systemic dimensions may help to prioritise, e.g. by focusing efforts on identifying critically important ecosystems and the different risk transmission channels that stem from them. These considerations include:

- **Compounding effects:** The degradation of one ecosystem or ecosystem service may trigger a degradation or a collapse of others[51]. To illustrate, the collapse of globally important ecosystems like the Amazon may disrupt other ecosystems at a global level, including via effects on climate change. Physical and transition risks also interact over time. In particular, the loss of certain ecosystems may trigger local, regional or global policy responses that result in transition risk.
- **Cascading effects:** Physical and transition risks may cascade and amplify via value chains (included in the Framework as part of phase 2 under Direct and indirect effects). When taking a sector-based approach to prioritisation, this systemic dimension should particularly be kept in mind to avoid an underestimation of risk[52].
- **Contagion:** The effect of physical and transition risks on individual financial institutions has the potential to spread throughout financial systems and/or create feedback loops to the real economy (included in the Framework as part of phase 3 under Contagion).

Climate-nature nexus

As already highlighted, nature is multifaceted, which, as stated previously, covers both biotic and abiotic elements such as water, land use, nitrogen and phosphorus flows, biodiversity as well as climate. Previous work of the NGFS has focused largely on climate, and firmly established the relevance of climate-related risks for central banks and supervisors. However, the relevance of the broader nature dimensions – described as environmental risks – has been recognised by the NGFS[53]. This has led to a positioning of climate and environmental risks as two distinct but interrelated issues.

The various dimensions of nature have unique features, and are distinct in some respects. However, it is important to recognise that the different dimensions of nature are

47 Recommendations toward the development of scenarios for assessing nature-related economic and financial risks, NGFS, December 2023; Prodani, J., *et al.* (2023) The economic and financial stability repercussions of nature degradation for the Netherlands: Exploring scenarios with transition shocks, DNB.; Ranger, N. & Oliver, T. (2024) Assessing the Materiality of Nature-Related Financial Risks for the UK.

48 For an example of a spatially-explicit study taking into account the location of exposures, see e.g. Hadji-Lazaro, p., *et al.* (2023) Socioeconomic and spatially-explicit assessment of Nature-related risks: The case of South Africa.

49 Final Report, NGFS-INSPIRE Study Group, March 2022. See also Crona, B., Folke, C., & Galaz, V. (2021) *The Anthropocene reality of financial risk*. One Earth.

50 See pp. 27-28 of the NGFS Technical Document on Nature Scenarios.

51 For instance, regulating and maintenance ecosystem services are complementary to one another, meaning that if one of them is disrupted sufficiently, the others will be disrupted as well. See *The Economics of Biodiversity: The Dasgupta Review*, February 2021.

52 For a recent example of an indirect exposure analysis, see Boldrini S., *et al.* (2023) *Living in a world of disappearing nature: physical risk and implications for financial stability,* ECB.

53 *A call for action – Climate change as a source of financial risk,* NGFS, 2019.

also closely interconnected[54]. Therefore, even as the NGFS continues its work in further understanding climate-related financial risks, it is equally important to consider risks stemming from climate and the other dimensions of nature in an integrated manner. To facilitate such an integrated assessment, nature-related financial risks as defined in this Framework incorporate the full spectrum of climate and environmental risks[55]. In other words, for the purposes of the Framework, climate-related risks are considered to be part of nature-related financial risks.

There may be pragmatic reasons why an integrated assessment of nature-related financial risks is not always possible or desirable (e.g., as a result of modelling challenges). Furthermore, from a practical perspective, climate-related financial risks are more established and will in many cases be the starting point for action on broader nature-related financial risks. To enable the shift towards an integrated assessment of nature-related financial risks, the Framework has therefore generalised the existing NGFS approach to climate where possible. In addition, the table below describes some of the key interlinkages between climate and broader-nature-related financial risks that could be considered when taking first steps toward a more integrated approach[56]. In short, the physical dynamics driving climate change and the degradation of nature are mutually reinforcing. Additionally, climate mitigation and nature restoration present potential trade-offs and synergies[57].

Connection	Description
Climate change as a driver of nature risk	Climate change, and the resulting rising global temperatures, is one of the main direct drivers of nature degradation. For example, increases in flooding, wildfires, ocean acidification and cyclones as a result of climate change can disrupt the water cycle, alter soil temperatures and accelerate habitat and wildlife loss.
Nature degradation as a driver of climate risk	Loss of key ecosystems increases the pace of climate change through adverse changes in the carbon, nitrogen, and water cycles. Additionally, the destruction of forests, peatlands, and other carbon-sequestering ecosystems may accelerate climate change through the release of long-stored carbon into the atmosphere alongside a reduced ability to sequester future carbon. The destruction of ecosystems such as wetlands or mangroves may also alter natural infrastructure that is important for climate resilience.
Climate change mitigation and adaptation as a potential driver of nature risk	Combating climate change can slow the climate-driven deterioration of ecosystems. But, certain strategies for climate change mitigation/adaptation and achieving net-zero goals have the potential to cause inadvertent negative effects on ecosystems. For example, biodiversity can be harmed by poorly planned tree planting to capture carbon dioxide emissions (e.g. of non-native species and monocultures), mining of materials for battery storage technology, destruction of natural areas to install solar installations, or land use changes to fulfil bioenergy needs (e.g. deforestation for wood or planting biofuel crops).
Nature as a solution to decrease climate risk (i.e. nature-based solutions[1])	Restoration and preservation of ecosystems contributes substantively to mitigating climate change and therefore plays a key role in achieving the goals of the Paris agreement. As suggested above, combatting deforestation and peatland destruction can prevent the release of stored carbon and facilitate future carbon sequestration. Conservation or extension of natural systems can also help to adapt to the effects of climate change (e.g. disaster risk reduction). For example, ecosystems such as wetlands, forests, mangroves and dune habitat increase resilience to physical shocks (e.g. storms, wildfires, landslides or floods) by providing protective barriers or buffers.

1 Nature-based Solutions are defined by the UN Environment Assembly (Resolution 5/5 of 2 March 2022) as: *"actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services, resilience and biodiversity benefits."*

54 Based on, *inter alia*: Final Report, NGFS-INSPIRE Study Group, March 2022; *Pörtner, H. O., et al. (2021) IPBES-IPCC co-sponsored workshop report on biodiversity and climate change.* IPBES and IPCC.

55 Kedward, K., Ryan-Collins, J., & Chenet, H. (2022) *Biodiversity loss and climate change interactions: financial stability implications for central banks and financial supervisors.* Climate Policy.

56 Based on, *inter alia*: Final Report, NGFS-INSPIRE Study Group, March 2022; *Pörtner, H.O., et al. (2021) IPBES-IPCC co-sponsored workshop report on biodiversity and climate change.* IPBES and IPCC.

57 Kedward, K., Ryan-Collins, J., & Chenet, H. (2022) *Biodiversity loss and climate change interactions: financial stability implications for central banks and financial supervisors.* Climate Policy.

Questions for members to consider when identifying sources of physical and transition risks:

1) **Current exposures:** Which direct and indirect dependencies does the economy and the financial sector (incl. via insured and financed activities) have on ecosystem services? Which direct and indirect negative impacts does the economy and the financial sector have on nature? Which of those dependencies and negative impacts could be material sources of physical and transition risk from a microprudential, macroprudential and/or macroeconomic risk perspective?

2) **Priorities:** What are the key sectors with the highest impacts and dependencies (both direct and indirect) on nature? What are the critical global, regional and/or local ecosystems these key sectors, or the economy/financial sector as a whole, interact with, and where are they located? What is the current or estimated state of these critical ecosystems?

3) **Forward-looking view:** Are there any future developments that should be considered when assessing sources of physical and transition risks such as emerging policy frameworks or the sudden collapse of one or more ecosystem services? Over what time horizon are these forward-looking developments expected to materialise?

4) **Climate-nature nexus:** How does the consideration of climate change (and related mitigation/adaptation strategies) affect the identification of potential nature-related financial risk? Could sectors with large dependencies or impacts on nature be contributing to climate change, or be affected by it? Which strategies for climate change mitigation have the potential to cause inadvertent negative effects on ecosystems, thereby amplifying nature-related financial risks?

Phase 2: Assess economic risks

Analysing exposures in phase 1 only provides an indication of potential physical and transition risks, which does not yet equate to a risk assessment. As a second step, central banks and supervisors could assess the potential economic effects and identify material economic risks that can stem from these exposures[58]. These may be relevant in their own right as macroeconomic risks (e.g., inflationary pressures) or transmit physical and transition risks to the financial sector. This section draws attention to **three elements that should at least be considered when assessing economic risks:** (i) direct and indirect effects; (ii) micro, sectoral/regional and macro effects; (iii) substitutability.

Direct and indirect effects

Physical and transition risks affect households and businesses via their direct dependence or impact on nature. This effect on primary producers (e.g. farmers) and consumers is also described as the direct effect (or first-order effects). However, the economic effects of physical and transition risks are not limited to direct effects. Instead, as also mentioned in phase 1, risks may cascade through value chains – and between sectors – to other parts of the economy and/or across borders. Indirect effects (or second-order effects) capture this transmission of direct effects via value chains.

Micro, sectoral/regional and macro level effects

Via direct and indirect transmission channels, physical and transition risks can have both microeconomic and macroeconomic effects. On a micro level, physical and transition risks can affect businesses and households dependent on ecosystem services to sustain their livelihood. For instance, households may suffer a loss of income and higher livelihood costs as a result of weather-related damages or the effects of nature degradation on health and productivity. On a macro level, physical and transition risks may have implications for prices, productivity, investment, socio-economic changes, fiscal balances and trade and capital flows (in particular affecting inflation and gross domestic product ("GDP")).

58 This phase shares similarities with the 'Assess' phase in the TNFD LEAP approach. For more information on measurement approaches, see also: Assessing biodiversity-related financial risks: Navigating the landscape of existing approaches, OECD, April 2023.

Micro level effects		Macro level effects
Capital destruction: Damage to assets arising from physical shocks and hazards such as flooding or landslides.	Regional/ sectoral level	Prices: Changes in prices of commodities, energy or water could create inflationary pressure.
Stranded assets: New regulations or changing consumer preferences resulting in premature write-offs of assets, for instance because a factory is located in an area that becomes designated as protected.		Productivity: Effects on GDP from a diversion of investment or lower risk appetites for innovation, reduced labour productivity (e.g. as a result of heat or pollution), the loss of provisioning or regulating service productivity (e.g. affecting agriculture) or damage and disruptions to assets.
Price volatility of raw materials: Higher or more volatile prices of commodities due to, for instance, failed harvests of food crops.		Capital: Higher investment needs for mitigation or adaptation to prevent nature degradation and potentially accelerated depreciation of the current capital base.
Disruptions of production processes and value chains: Increases in costs as a result of temporary disruption to businesses or households processes, such as a suspension of services due to flooding.		Socio-economic changes: Effects from structural changes to the economic system, changing societal preferences, arising inequalities, migration or conflict.
Relocation and adjustment of economic activities: Relocation or alteration of economic activities to account for a reduction or loss of ecosystem services, or to reduce negative impacts, such as planting different crops on a farm.		Trade and capital flows: Changes to trade and capital flows may result from shocks in ecosystem service provision, potentially amplified via value chains, which affects exchange rates and sovereign credit ratings.
Pricing of externalities: Cost increases as a result of pricing in negative (or positive) impacts on nature, for instance a tax on certain pollutants.		Fiscal balances: The lack of access to ecosystem services may require an increase in social protection spending on e.g. water or food. Losses in production and employment may also reduce fiscal revenues.

The micro and macro level effects are not isolated. Microeconomic effects can translate into macroeconomic effects, while macroeconomic effects also can in turn affect households and businesses (potentially giving rise to feedback loops). Introduction of a sectoral/regional level effects in the analysis might be beneficial to better capture these dynamics (see also figure 2). The table above highlights some of the key economic effects[59]:

Substitutability

To assess the economic effects and risks, it is relevant to account for the fact that actors react differently to shocks depending on their sensitivity to the shock and their ability to adapt[60]. The notion of substitutability is particularly relevant in that regard. Two dimensions can be distinguished: geographical substitution and technological substitution.

- **Geographical substitution (i.e., between ecosystem services):** In the case of direct effects, the ability to adapt and rely on different ecosystem services may be limited. For example, when ecosystem services decline in a particular location, it could require a business to move its operations (with economic implications for the affected region) or make expensive alterations to its production processes. Businesses which are indirectly affected – i.e., through their value chain – may be in a better position to substitute, for example by changing suppliers or using different products (although such substitutes may not always exist). Consequently, jurisdictions or businesses with a higher reliance on primary sectors could be more exposed to economic effects[61]. At the same time, the large scale global degradation of ecosystems could make it increasingly difficult to find alternative sources of the required ecosystem services, including for jurisdictions and businesses that are indirectly exposed.

59 Based on, *inter alia*: *Indebted to nature: Exploring biodiversity risks for the Dutch financial sector*, DNB and PBL, 2020; *Handbook for Nature-related Financial Risks*, Cambridge Institute for Sustainability Leadership ("CISL"), 2021; Final Report, NGFS-INSPIRE Study Group, March 2022. For further examples, see also A Supervisory Framework for Assessing Nature-related Financial Risks – Identifying and navigating biodiversity risks, OECD, 2023.

60 Final Report, NGFS-INSPIRE Study Group, March 2022; Svartzman, R., *et al.* (2021) *A "Silent Spring" for the Financial System? Exploring Biodiversity-Related Financial Risks in France;* Recommendations toward the development of scenarios for assessing nature-related economic and financial risks, NGFS, December 2023.

61 See for instance: Johnson, J. A., *et al.* (2021) *The Economic Case for Nature: A Global Earth-Economy Model to Assess Development Policy Pathways.* The higher decline in GDP that was measured for low-income and lower-middle-income countries was due, in part, to a high dependency on forestry or pollinated crops along with limited possibilities to switch to other production and consumption options.

- **Technological substitution (i.e., between natural and manufactured/human capital):** There is a broader question to consider around the ability of businesses to adapt to physical shocks by substituting the loss of ecosystem services with technologies and other alternatives. For example, loss of pollinators may be replaced by mechanical pollination technologies. But if nature cannot be fully substituted – or substituted at all – the effects of losing ecosystem services will be far larger than if replacement technologies are used. Assumptions on the availability of replacement technologies in a particular sector or region are therefore important because they influence the size of estimated potential economic effects. Standard macroeconomic models generally assume a high degree of possible substitutability, and therefore have tended to estimate relatively small economic costs of nature degradation as a percentage of GDP[62]. Given that a broad academic literature has argued that substitution possibilities may be limited or even impossible for environmental goods and services (including, regulating and maintenance services), models may therefore need to embrace the possibility that nature cannot be – or not easily be – substituted[63].

When accounting for substitution, it may be appropriate to consider how adaptation possibilities might change over time and at what scale. For instance, there may be very low or even no adaptation options in the short-term period following a physical shock (e.g. due to contractual obligations, entrenched consumer preferences or technological limitations). However, this might change as replacement technologies become available over the medium term. Equally, it is possible to imagine some substitution possibilities for quite small changes in ecosystem services, but these might reduce drastically for substantial nature degradation (such as those resulting from tipping points). Other factors such as costs (especially in the short run) and negative impacts on nature may also influence the availability and effects of substitutes over time.

Questions for members to consider when assessing economic risks:

1) **Value chains:** Where are the direct economic effects located (domestically or abroad)? Can direct effects transfer across borders and/or amplify (including domestically) through value chains, thereby resulting in indirect economic effects? Can risks cascade to different value chains?

2) **Micro-macro interaction:** To what extent do economic effects on households and businesses as a result of nature-related financial risks lead to macroeconomic deterioration, including lower productivity or inflationary pressures? Are there any risks that directly create effects at the macro level? Could macroeconomic deterioration affect or create a feedback loop to the micro level?

3) **Vulnerability, adaptation and substitution:** How vulnerable are economic actors given their ability to adapt (e.g. via substitution)? For the identified economic transmission channels, what technological or geographical substitution possibilities are available that could mitigate the effects of shocks and hazards? How would these possibilities change as the size of the shock or hazard increases?

62 The Economics of Biodiversity: The Dasgupta Review, February 2021. See also Recommendations toward the development of scenarios for assessing nature-related economic and financial risks, NGFS, December 2023; Svartzman, R., *et al.* (2021) *A "Silent Spring" for the Financial System? Exploring Biodiversity-Related Financial Risks in France.*

63 Recommendations toward the development of scenarios for assessing nature-related economic and financial risks, NGFS, December 2023 (referencing: The Economics of Biodiversity: The Dasgupta Review, February 2021; Neumayer, E.; (2013) Weak versus Strong Sustainability: Exploring the Limits of Two Opposing Paradigms. Cheltenham: Edward Elgar Publishing.

Phase 3: Assess risk to, from and within the financial system

As a third step, central banks and supervisors may want to consider the financial risks that stem from the exposures to sources of physical and transition risks (directly, or more likely, via financed activities)[64].

Effects on the financial system

The effects of nature degradation and related policies on the economy can transmit to financial institutions and can have an impact on the financial system. Similar to climate-related risks, they can lead to the impairment of assets and collaterals; lower corporate profitability and the impairment of insurability, affecting traditional financial risk categories. The table below illustrates this[65].

Prudential risk categories	Examples of potential nature-related factors affecting prudential risks
Strategic and business model risk	The loss of ecosystems affects the ability of pharmaceutical companies to rely on particular natural resources for their drug development or production.
Credit risk	Soil degradation affects agricultural productivity, influencing the collateral value of agricultural land or the ability of farmers to repay debt.
Market risk	The market value of a company is affected by assets that have decreased in value because there is insufficient fresh water for the production process, or the value of the business' production process is reduced by the emergence of new technologies that require less water to operate.
Underwriting risk	Pandemic causes more claims under insurance than usual or soil erosion leads to more damaging effects of floods.
Operational risk	Financial institution faces reputation or litigation risks as a result of financing a company engaged in activities that contribute to deforestation. Facilities/suppliers of the financial institution are affected by flooding or landslides.
Liquidity risk	There may be pressure to liquidate assets due to rapid nature degradation as a result of crossing a tipping point or new regulations affecting particular assets that influence cash flows and collateral values.

Contagion

The effect on individual financial institutions has the potential to spread throughout financial systems and/or create feedback loops to the real economy. These dynamics may amplify shocks that are initially relatively mild, but may have the potential to propagate across financial institutions and therefore merit consideration. Similarly, shocks that affect financial stability could trigger further macroeconomic deterioration, e.g. via market losses or credit tightening[66]. Potential examples might include inflationary shocks from rising food prices causing a rise in interest rates and weakening balance sheets of financial institutions such as banks. Likewise, uncertainty around policy measures could affect credit conditions and therefore the ability of economic actors in the system to transition. Factors that would influence the level of contagion include the market concentration of businesses withing high-risk sectors, the concentration of exposures to high-risk sectors within the financial system, the interconnectedness of highly exposed financial institutions and the presence of information asymmetries between economic actors[67].

Endogenous risk: effects of the financial system on nature

Economic actors are not only exposed to nature-related physical and transition risks. Via the negative impacts they have on nature, these actors also contribute to the risks they need to manage. That effect is not always symmetrical.

64 Like Phase 2, this phase shares similarities with the 'Assess' phase in the TNFD LEAP approach.

65 Based on, *inter alia*: Final Report, NGFS-INSPIRE Study Group, March 2022; *Indebted to nature: Exploring biodiversity risks for the Dutch financial sector,* DNB and PBL, June 2020; *Handbook for Nature-related Financial Risks Key concepts and a framework for identification,* CISL, 2021. For further examples, see also A Supervisory Framework for Assessing Nature-related Financial Risks – Identifying and navigating biodiversity risks, OECD, 2023.

66 Interim Report, NGFS-INSPIRE Study Group, October 2021.

67 A Supervisory Framework for Assessing Nature-related Financial Risks – Identifying and navigating biodiversity risks, OECD, 2023.

Some businesses may have a large negative impact on nature but are not most directly and significantly exposed to the physical risks stemming from nature degradation. Instead, they increase physical risks for the system as a whole[68]. Those activities that give rise to endogenous risks are also likely to be a source of transition risks when the negative impacts attract the attention from policy makers, innovators, investors or consumers.

The financial sector is not solely responsible for economic activities that exert negative impacts on nature, but it does play a role as enabler of economic activities. In this context, it should be noted that economic actors may also exert a positive impact on nature via their activities, e.g. by financing activities that contribute to the conservation and restoration of nature and thereby decreasing physical risks.

Questions for members to consider when assessing financial risks:

1) **Transmission:** How can economic risks transmit to traditional financial risk categories?

2) **Systemic dimension:** How can nature-related financial risks amplify via feedback loops within the financial sector, or between the financial sector and the real economy?

3) **Endogenous risk:** Is the financial sector materially contributing to the physical risks to which it is exposed to?

68 Final Report, NGFS-INSPIRE Study Group, March 2022.

4. Pathways to action

By providing a common understanding of nature-related financial risks and a principle-based risk assessment approach, this document has created a shared framework for central banks and supervisors to assess the interactions between nature, the macroeconomy and the financial system in a way that is intended to be actionable.

To assist with the operationalisation, the Framework includes two illustrative cases which demonstrate how the various steps and guiding questions included in the risk assessment framework can be applied (see Illustrative Cases). The Framework is also complemented by the NGFS Technical Document on Nature Scenarios. This document contains further information on methodologies to identify relevant forward-looking physical and transition shocks, as well as detailed information on models that can be used to assess the economic and financial risks that stem from them. The recommendations in that Technical Document, as well as examples provided in this Framework and tools highlighted in supplementary frameworks produced by the OECD[70] and TNFD[71], provide relevant data sources, methods and tools that may help central banks and supervisors move from a conceptual understanding to a data driven assessment of nature-related financial risk. These documents will not have all the relevant answers and tools. But by taking first steps, central banks and supervisors can provide important methodological contributions to help refine those data and methods over time.

In the meantime, the Framework and its guiding questions may be used to facilitate a dialogue with the financial sector about the identification, assessment, management and disclosure of nature-related financial risks. In light of this, it will be relevant to consider how the Framework could inform – and be made interoperable with – efforts of stakeholders beyond the NGFS such as regional and global standard setters (e.g., the Basel Committee on Banking Supervision ("BCBS"), the Financial Stability Board ("FSB") and the International Association of Insurance Supervisors ("IAIS")).

To conclude, considering the relevance of nature-related financial risks for their mandates[72], central banks and supervisors are encouraged to identify, assess and – where relevant – act on material economic and financial risks stemming from dependencies and impacts on nature and their nexus with climate change. While doing so, differences in mandate, capacity, experience and context should be taken into account. These differences not only inform the starting point, but can also enrich the understanding of nature-related financial risks and the spectrum of actions available to address them. This Framework is intended as a common starting point for such action across the NGFS membership.

70 A Supervisory Framework for Assessing Nature-related Financial Risks – Identifying and navigating biodiversity risks, OECD, 2023.

71 Recommendations of the Taskforce on Nature-related Financial Disclosures, TNFD, 2023; Tools Catalogue, TNFD.

72 *Statement on Nature-Related Financial Risks*, NGFS, 24 March 2022.

Illustrative Cases

Introduction to the illustrative cases

To assist with the use of the principle-based risk assessment framework, this section illustrates the application of the guiding questions to two examples of specific ecosystems ("Illustrative Cases"). The Illustrative Cases are intended to demonstrate, in a largely qualitative way, how the three phases in the Framework can be navigated. In doing so, findings are incorporated from existing academic literature, newspaper articles, analyses and tools such as ENCORE and WWF risk filters to arrive at a best-effort understanding of the relevant nature-related financial risks related to those ecosystems[73].

By providing colour to the to the potential use of the phases and guiding questions, the Illustrative Cases showcase how the structure of the Framework may help to break down the complexity of nature-related financial risk assessments into manageable parts. In doing so, these Illustrative Cases seek to facilitate the assessment of nature-related financial risks by central banks and supervisors. Importantly, the Illustrative Cases are not intended to be prescriptive. Nor is an attempt made to offer comprehensive risk assessments for these ecosystems, the jurisdictions in which they are located, or sectors that may depend on or impact these ecosystems. This would require, among other things, substantive further analysis such as quantitative assessments. For guidance on such quantitative assessments and forward-looking recommendations in this regard, reference is made to the Technical Document on Nature Scenarios[74]. The jurisdictions covered by the illustrative cases do not necessarily endorse the analysis or have responsibility for adopting its conclusions.

The two Illustrative Cases are based on a freshwater ecosystem and a forest ecosystem. In phase 1 of the framework, it is highlighted that central banks and supervisors may wish to prioritise certain sectors or ecosystems are more likely to be sources of material risks. For the Illustrative Cases, an ecosystem-based approach was adopted. Without prejudice to the relevance of other types of ecosystems, the Illustrative Cases were based on freshwater ecosystems and forests for the following reason: (i) several national and regional impact and dependency studies highlight the potential economic importance of the ecosystems services provided by freshwater and forest ecosystems; (ii) degradation of these ecosystems and pressure affecting them present recognizable examples of nature-related financial risks; and (iii) the degradation of these ecosystems is closely linked to climate change, offering an opportunity to highlight the climate-nature nexus.

The specific ecosystems selected for the Illustrative Cases are the Colorado River Basin in North America and the Amazon Rainforest in South America. This selection is based on their large size, prominence and the availability of existing ecological and economic research on these ecosystems. The use of these examples does not imply a view that these are the most critical ecosystems from an economic or financial risk perspective. Instead, they are merely two of many ecosystems that could be used for future examples or studies. Examples include the Nile, Rhine, Yangtze, Ganges and Congo Rivers, wetlands such as the Pantanal in Brazil or lake Chilwa wetland in Malawi as well as other rainforests such as the rainforests of Southeast Asia and the Congo Basin.

When assessing risks related to such other ecosystems, research and data may not always be readily available. In those situations, the Illustrative Cases could provide inspiration to find relevant materials, to search for information on similar ecosystems that could serve as a proxy and/or to leverage expertise held by local experts and institutions. Even if this does not result in a comprehensive assessment, it may help to answer already some of the guiding questions and provide a starting point to progressive improve the understanding of the relevant nature-related financial risks.

73 Those efforts included an extensive search for relevant publicly available materials as well as feedback on the initial findings by members of the Task Force and outside experts. Despite those efforts to arrive at a balanced at sufficiently comprehensive understanding of potential nature-related financial risks, the information presented in the Case Study is merely intended to provide a starting point and should not be considered as exhaustive.

74 *Recommendations toward the development of scenarios for assessing nature-related economic and financial risks*, NGFS, December 2023.

Phase 1

Identify sources of physical and transition risks

1. Current exposures

- The Amazon is **home for over 30 million people** and hosts 40% of the world's remaining rainforest
- Offering a wide range of provisioning services (timber, food, freshwater), regulation (including for climate), cultural and supporting services
- Economic actors primarily exert negative impacts on the Amazon **via land use change (deforestation), pollution and climate change**

2. Priorities

- **Agriculture and mining** are the sectors with the highest direct impacts and dependencies on the Amazon
- Increased tree mortality, deforestation, pollution, and anthropogenic global warming **could push the Amazon past critical thresholds**

3. Forward-looking view

- **26% of the Amazon** is already showing evidence of physical risks (deforestation and degradation)
- Legislation, regulation and shifting public sentiment towards preservation of the Amazon imply **an increase in transition risks**

4. Climate-nature nexus

- **Climate change** has increased aridity and fires in the Amazon while deforestation has changed the Amazon into a source of carbon emissions
- Mitigation efforts that rely on mining for transition critical minerals, advanced biofuel production and construction of dams can increase **nature degradation**

Phase 2

Assess economic risks

1. Value Chains

- **Agriculture and mining** are particularly affected
- Regional economic effects of degradation -eg. supply constraints- could affect global output and prices
- Global dependency on commodities produced in the Amazon can be **disrupted with policy responses**, (eg. banning of non-deforestation-free products), resulting in transition risk

2. Micro-macro interaction

- At the macro level, deforestation could induce an increase in **productivity losses** and decreases in employment levels
- Macro level deterioration could result **in feedback loops** at the micro level, ie. via impact on the price of housing or consumer goods

3. Vulnerability and substitution

- The vulnerability of economic actors depends on their **ability to adapt**
- **Substitution options** for the agricultural, energy and transportation sectors include a switch to agroforestry, advanced technologies, and transition towards alternative sources of power
- Substitution possibilities are **uncertain and become more limited or** even chronically impaired as the size of the hazard increases.

Phase 3

Assess risk to, from and within the financial system

1. Transmissions

- Economic risks can transmit **via traditional risk categories** for financial institutions (business risk, decrease in credit worthiness, operational risk linked to potential litigation, market risk linked to repricing and volatility for firms impacted by forest degradation)

2. Systemic dimension

- The combination of **interconnectedness between FIs and concentrated exposition** to the agricultural sector could trigger risk propagation
- Contagion could occur because of divestment threats linked to physical risks, or via litigation risks
- The decrease in investment linked to Amazon degradation could **create feedback loops** that would be detrimental to agricultural productivity

3. Endogenous risks

- The financial sector finances activities that **contribute to the degradation of the Amazon**, eg. beef or soy bean, thereby amplifying the physical risks to which they or other actors are exposed

Forests Illustrative Case: The Amazon Rainforest

Tropical rainforests are both ecologically and economically important. To illustrate, it is estimated that the net benefit to the world economy of a 50% reduction of tropical forest deforestation and degradation is as much as USD 3.7 trillion[75]. One particularly important tropical rainforest is the Amazon Rainforest (the "Amazon") that spans over nine jurisdictions in South America. It hosts 40% of the world's remaining rainforest, 25% of its terrestrial biodiversity and more fish species than any other river system[76]. For each of these nine jurisdictions, the Amazon is integral to the health of the economy and local communities. It is estimated that over 30 million people depend directly or indirectly on the Amazon for their wellbeing[77]. The Amazon also exerts a global impact via its influence on the global carbon cycle, hydrological systems and as a habitat for species. For instance, the Amazon is found to act as 'wind brake' reducing the occurrence of hurricanes and anomalous weather patterns across South America. By pumping moisture into the air, it also regulates precipitation patterns far outside the Amazon region[78]. By going through the phases in the risk assessment framework, the following sections illustrate how the degradation of the Amazon could result in economic and financial risks.

Phase 1: Identifying sources of nature-related financial risk

Summary of phase 1

This phase identifies the key sources of risks that stem from the degradation of the Amazon. It highlights the wide range of key ecosystem services provided by the Amazon on a local and global level, ranging from cultural significance for local populations, the provision of food as well as global climate regulation. The analysis draws attention to deforestation and pollution as two key drivers of the Amazon's degradation and agriculture, forestry and mining as high impact sectors. Nature-related financial risks are likely to increase due to climate change and emerging policies aimed at halting deforestation. The construction of dams, farming of biofuels, and mining of minerals needed for the energy transition are some of the key activities that could be positive from a climate perspective but also contribute to the degradation of the Amazon.

Q1.1 Current exposures

The global economy and the financial system depend on a number of ecosystem services provided by the Amazon. For instance, the Amazon regulates freshwater and soil quality which is critical to the agricultural sector. The Amazon also provides timber, minerals and biodiversity conservation that is used in forestry, mining, and pharmaceutical research. Globally, the Amazon plays a critical systemic role in climate regulation and carbon sequestration. Its dieback is associated with crossing climate tipping points. Key ecosystem services provided by the Amazon include the below (for further information on impacts and dependencies on forests, see also Annex 4):

- **Provisioning services**: Supply of timber, food and freshwater (ground and surface).

75 Hope, C. & Castilla-Rubio, J. C. (2008) *A first cost benefit analysis of action to reduce* deforestation. Working paper series, Cambridge Jude Business School.

76 *Why the Amazon's Biodiversity is Critical for the Globe: An Interview with Thomas Lovejoy,* The World Bank, May 2019.

77 Johnson, J. A., *et al.* (2021) *The Economic Case for Nature: A Global Earth-Economy Model to Assess Development Policy Pathways.* The WWF estimates the number of people reliant on the Amazon at over 40 million (Amazon, WWF, webpage retrieved from: https://www.worldwildlife.org).

78 Vourlitis, G. L., *et al.* (2002) *Seasonal variations in the evapotranspiration of a transitional tropical forest of Mato Grosso, Brazil.* Water Resources Research.

- **Regulating services**: Climate regulation, air and water filtration, biodiversity conservation (including for pharmaceutical research and development) as well as soil quality regulation (including for local agriculture).
- **Cultural services:** Cultural and spiritual significance for local populations, recreational opportunities and tourism.
- **Supporting services:** Soil and sediment retention, flood and storm protection and nutrient cycling[79].

Several economic actors exert negative impacts on the Amazon via land use change (deforestation), pollution and climate change[80]:

- Deforestation is one of the biggest threats to the Amazon with over 20% of the Amazon deforested (a measurement stemming from 2022 compared to pre-1970 levels). 38% of the remaining forest is considered degraded[81]. Agriculture, forestry, and mining are the key sectors responsible for deforestation activities. Other drivers of degradation in the Amazon include illegal logging, land grabbing, cattle ranching[82], urbanisation, human settlement and associated infrastructure development, forest fires (human-induced or natural[83]) and climate change[84].
- Pollution is another key driver of the Amazon's degradation. Mining particularly contributes to pollution, notably via the use of mercury[85]. Globally, it has been estimated that approximately 35% of the total release of mercury from artisanal and small scale gold mining is directly emitted into the atmosphere, while the remainder is released into the water[86]. Forest fires, agricultural burning and industrial activities also contribute to harmful levels of pollution in the Amazon[87]. These particles are detrimental to the health of animals and local populations[88].

To illustrate the size of high impact activities, five of the jurisdictions in the Amazon region (Brazil, Columbia, Ecuador, Bolivia and Peru) obtain 70% of their gross national product (GNP) from agribusiness, hydropower and heavy industry[89].

Q1.2 Priorities

Agriculture and mining rank as the sectors with highest direct impacts and dependencies on the Amazon.

Large scale agriculture and cattle raising has the highest direct impacts and direct dependencies[90]. Agriculture is directly dependent on the provision of land and healthy soil for growing crops and grazing livestock. Indirectly, the Amazon provides a habitat for key pollinators which agricultural practices rely on. Crop production dependent on animal pollination has increased in the Amazon by 300% over the past 50 years[91]. Due to the large scale of agricultural operations in the region, the impact of the sector's operations on the Amazon is also large. In 2020, more than 235,000 square kilometres were used for crop production in the Amazon[92]. Since the 1960s, the cattle herd of the Amazon region has increased from 5 million to more than 70-80 million heads and 80% of deforested areas have been covered by pastures (approximately 900,000 km^2)[93]. Total deforestation and conversion of native vegetation across Brazil increased from 1.6 million hectares in 2018 to 1.83 million hectares in 2020, making the expansion of pasture for cattle farming and land speculation the largest direct driver of deforestation and conversion[94]. The use of agrochemicals from the plantations contribute to this impact by contaminating the soil.

79 *Mechanized Agriculture*, WWF, webpage retrieved from: https://wwf.panda.org/.

80 Not all economic actors exert such negative impacts. For instance, many indigenous peoples have traditionally lived in harmony with the Amazon rainforest, often practicing sustainable land management techniques that support their communities without causing deforestation.

81 Camargo, S. *Invisible destruction: 38% of remaining Amazon forest already degraded*. Mongabay, February 2023.

82 *Deforestation Fronts, Drivers and Responses in a Changing World*, WWF, 2021.

83 Pristine rainforest does not burn easily due to its humidity. Usually some level of deforestation or degradation is needed for fires to take hold.

84 Lapola, D. M., *et al.* (2023) *The drivers and impacts of Amazon forest degradation*, Science.

85 Crespo-Lopez, M. E., *et al.* (2023) *Mercury in the Amazon: The danger of a single story*, Ecotoxicology and Environmental Safety.

86 Telmer, K. H. & Veiga, M. M. (2009) *World emissions of mercury from artisanal and small scale gold mining*, Mercury Fate and Transport in the Global Atmosphere.

87 Fine particulate matter is defined as particles that are 2.5 microns or less in diameter.

88 *Breathless in the Amazon: How PM2.5 Pollution is Harming Wildlife in Brazil's Rainforest*, AQI, March 2023.

89 *Human security impacts of crossing the Amazon rainforest tipping point*, GermanWatch, February 2023.

90 One can prioritize sectors with high impacts and high dependencies by making use of the WWF Biodiversity Risk Filter (BRF) (*Biodiversity Risk Filter*, WWF). The WWF BRF proves prioritization tools based on the sector materiality (using the TNFD approach) and location.

91 *The assessment report on Pollinators, Pollination and food production*, IPBES, 2016.

92 *Area planted or destined to harvest in the Legal Amazon in Brazil from 2000 to 2020*, Statista, August 2023.

93 Veiga, J. B., *et al.* (2003) *Cattle Ranching In The Amazon Rainforest*, XII World Forestry Congress.

94 Reis T., Ermgassen, E. Z., and Pereira, O,. *Brazilian beef exports and deforestation*, Trase, November 2023.

In addition to agriculture, mining has very high impacts and dependencies on the Amazon. The Amazon contains many minerals such as iron, copper, bauxite, nickel, tin, zinc, manganese and gold. The mining of these minerals exerts a large negative impact on the Amazon via deforestation and via polluted water with run-off from the mine affecting local ecosystems and communities[95]. To illustrate, the increase in the price of gold over the last decade has led to a new rush to mine in the Amazon. In Peru alone, at least 64,000 acres has been deforested for gold mining[96]. Mining activities in the Amazon may increase as a result of increased demand for minerals that are critical to energy transition. It is estimated that the mining of minerals such as lithium, cobalt, nickel and graphite that are needed for batteries could quadruple by 2040[97].

Q1.3 Forward looking view

The 'Amazon dieback' is a tipping point in the Earth's climate system. When crossed, physical risks may increase rapidly and give rise to acute risks. This 'Amazon dieback' refers to a significant reduction in the number of trees in the rainforest which disrupts its ability to sustain itself by transporting moisture. As more trees die due to water scarcity, the Amazon gradually transitions into a drier ecosystem, eventually transforming into a dry savannah. Increased tree mortality, deforestation and anthropogenic global warming could push the Amazon past these critical thresholds beyond which feedback loops propel abrupt and substantial forest loss[98]. The exact timeline in which these non-linear impacts could occur is deeply uncertain. However, with 26% of the Amazon already showing evidence of deforestation and degradation, and assuming recent trends continue, tipping points in the Amazon could already be crossed in the short to medium term[99].

A sudden collapse of the Amazon would non-linearly increase physical risks, forcing sectors with direct dependencies on ecosystem services from the Amazon to abruptly shift their operations. But gradual and acute transformations of the Amazon also affects its role as regulator of both regional and global climate and hydrological cycles[100]. Future changes to precipitation patterns and rainfall throughout North and South America as a result of the Amazon's degradation may impact water dependent sectors in these regions such as agriculture. The loss of resilience also has significant global implications for biodiversity, carbon storage and climate change and may result in changes to global weather patterns[101]. Those changes can have compounding effects on other ecosystems across the globe.

Legislation and regulation to preserve Amazon continue to emerge, increasing transition risks for industries with impacts and dependencies on the Amazon. In 2021, at the COP26 World Leaders Summit 'Action on Forests and Land Use', over 130 leaders representing more than 90% of the world's forests committed in the Glasgow Leaders' Declaration on Forests and Land Use to prevent forest loss and implement binding targets and clear measurements by 2030[102]. In addition, target 3 of the Global Kunming Biodiversity Framework ("GBF") seeks to, among other things, conserve 30% of land by 2030 which could include lands within the Amazon[103]. Rules stemming from this agreement may pose potential transition risk. Furthermore, starting from the end of 2024, the EU Deforestation Regulation will prohibit placement of relevant products on the EU market unless they are 'deforestation-free'[104]. Local legislation in the Amazon may also become more stringent for firms whose activities negatively impact the Amazon. In 2020, Brazil's National Monetary Council required land

95 Albert, J.S., *et al.* (2023) *Human impacts outpace natural processes in the Amazon*, Science.

96 Sonter, L. J., *et al.* (2017) *Mining drives extensive deforestation in the Brazilian Amazon*, Nature Connections.

97 *The Role of Critical Minerals in Clean Energy Transitions*, International Energy Agency, March 2022.

98 Boulton, C. A., Lenton, T. M., & Boers, N. (2022) *Pronounced loss of Amazon rainforest resilience since the early 2000s*, Nature Climate Change.

99 Praeli, Y. S., *The Amazon will reach tipping point if current trend of deforestation continues*, Mongabay, October 2022. For more information on the Amazon tipping point, see Lovejoy, T. E. & Nobre, C. (2019) *Amazon tipping point: Last change for action*, Science Advances.

100 *Amazon Assessment Report 2021, Chapter 7 Biogeophysical Cycles: Water Recycling, Climate Regulation*, The Science Panel for the Amazon, 2021.

101 Boulton, C. A., Lenton, T. M., and Boers, N., (2022) *Pronounced loss of Amazon rainforest resilience since the early 2000s*, Nature Climate Change; Aruajo, R. and Mourão, J. (2023) *The Amazon Domino Effect: How Deforestation Can Trigger Widespread Degradation*, The Climate Policy Initiative.

102 *COP26: Pivotal Progress Made on Sustainable Forest Management Conservation*, United Nations Climate Change, November 2021.

103 *Kunming-Montreal Global biodiversity framework (CBD/COP/DEC/15/4)*, December 2022.

104 *Green Deal: New law to fight global deforestation and forest degradation driven by EU production and consumption enters into force*, European Commission, June 2023.

and environmental regularisation as a prerequisite for granting credit[105].

Shifting public sentiment and pressures from consumers and investors can also be a source of transition risk. There has been increased pressure for companies and financial institutions to manage and disclosure risks associated with deforestation. To illustrate, over a thousand companies disclosed on their management of deforestation globally in 2022, representing a 300% increase relative to 2017[106]. Such pressure may also translate into increased litigation risk, which is considered a subset of transition and physical risk in the Framework.

Q1.4 Climate-nature nexus

Risks related to climate change are closely interconnected with a broader set of nature-related financial risks that stem from the degradation of the Amazon. Climate change is a key driver amplifying the degradation of the Amazon. However, deforestation in the Amazon also significantly contributes to the release of greenhouse gases and reduces carbon sequestration. Protection of the Amazon and sustainable reforestation could therefore contribute to a reduction of climate-related financial risks and broader nature-related financial risks at the

Connection	Description
Climate change as a driver of nature risk	• Globally, forest degradation has increase as a result of forest fires[1]. Specifically, climate change has increased the aridity of forest during the fire season due to increases in temperatures and drier conditions[2]. Recent research shows that since 2001, between 40,000 and 73,400 square miles of the Amazon have been impacted by fires[3].
Nature degradation as a driver of climate risk	• Deforestation contributes to the emission of greenhouse gases. Globally, this makes up about 10% of all human-induced GHG emissions[4]. Deforestation has changed the Amazon from a carbon sink to a source of carbon emissions[5]. Over the past 20 years, the Brazilian Amazon has emitted 13% more CO_2 than it has absorbed[6]. • Land use change, including via agriculture, reduces the ability of the soil in the Amazon to store carbon. • Wildfires in the Amazon contributed to the highest carbon emissions in 2022 compared to the past 20 years[7].
Climate change mitigation and adaptation as a potential driver of nature risk	• Clean energy technologies rely on critical minerals that are environmentally costly to mine. Mining activities in the Amazon damage natural resources by emitting greenhouse gas emissions, pollutants and contributing to deforestation. • Advanced biofuel production (notably soy, maize, and sugar cane) increases pressure on nature via land use change[8]. • Construction of dams for hydroelectric projects disturbs river connectivity and the health of wildlife populations in or around those rivers[9].
Nature as a solution to decrease climate risk	• The Amazon can contribute to climate change mitigation by acting as carbon sinks. The flora contained in the Amazon region absorb 1.5 bn tonnes of CO_2 a year, equivalent to 4% of global emissions from fossil fuels.

1 Tyukavina, A., *et al.* (2022) *Global Trends of Forest Loss due to Fire From 2001 to 2019,* Remote Sensing Time Series Analysis.

2 *Wildfire climate connection,* National Oceanic and Atmospheric Administration, July 2023.

3 Feng, X., *et al.* (2021) *How deregulation, drought and increasing fire impact Amazonian biodiversity,* Nature.

4 *Emissions Gap Report 2018,* United Nations Environment Programme, November 2018.

5 *The Brazilian Amazon has been a net carbon emitter since 2016,* The Economist, May 2022.

6 Gatti, L. V., *et al.* (2021). *Amazonia as a carbon source linked to deforestation and climate change*. Nature.

7 *Wildfires: Amazonas records highest emissions in 20 years,* The Copernicus Atmosphere Monitoring Service, October 2022.

8 Killeen, T. J., *Biofuels in the Pan Amazon,* Mongabay, November 2023.

9 Zanon, S., *Dam-building spree pushes Amazon Basin's aquatic life closer to extinction,* Mongabay, June 2023.

105 Estimates indicate that these measures affected economic actors operating in the region. The total deforested area was approximately 50-60% smaller than it would have been without these regulatory changes. See Assunção, J., *et al.* (2020) *The effect of rural credit on deforestation: Evidence from the Brazilian Amazon*. The Economic Journal.

106 *The Forest Transition: from Risk to Resilience, Global Forests Report 2023*, CDP, July 2023.

same time. But trade-offs can occur. Certain solutions to combat climate change can amplify the degradation of the Amazon and potentially increase nature-related financial risks. A notable example includes the mining of minerals critical for the energy transition. The table above provides further detail on these connections.

Phase 2: Assess economic risks

Summary of phase 2

This phase highlights how some of the economic risks related to the degradation of the Amazon can be identified. The assessment illustrates how agriculture and mining are particularly affected but also households due to the important role the Amazon plays in the provision of food and water for local communities. In the assessment, it is illustrated how macroeconomic deterioration might occur both regionally and globally due to the constraint production and supply of commodities from the Amazon. Geographical and technological substitutions possibilities may exist to replace ecosystem services that are lost or reduced. These substitution options are, however, likely to be very limited because of factors such as the importance of the Amazon to global climate regulation, the degradation of tropical forests elsewhere worldwide and the size of shocks affecting the Amazon.

Q2.1 Value chains

Economic risks from degradation of the Amazon can occur both domestically and abroad. As the Amazon spans multiple jurisdictions, several economies will experience direct effects in dependent sectors like agriculture and mining. These direct effects can transfer across borders and to other sectors through value chains, thereby resulting in indirect economic effects. For example, large quantities of commodities produced in the Amazon are exported to China, Europe, the United States and other countries[107]. Many of these commodities, such as soybeans, are used as inputs for several other products including animal protein feed, vegetable oil, and non-food uses in manufacturing[108]. These effects are in addition to the implications that the degradation of the Amazon could have on economies abroad as a result of, among other things, global temperature rise and changes in weather patterns (compounding effects which are highlighted in Phase 1).

The NGFS Technical Document on Nature Scenarios includes a case study on the potential direct and indirect economic effects of an EU transition policy to ban non-deforestation-free products. Using Multi-Regional Input-Output (MRIO) tables, the case study estimates that direct and indirect upstream effects would expose all Brazilian sectors to a potential reduction in total output of EUR 1.6 billion. The indirect downstream impact of such a policy measure would expose EUR 960 million of EU imports to this shock[109].

Q2.2 Micro-macro interaction

Through value chains, regional direct an indirect economic effects could affect macroeconomic variables such as global output and prices[110]. Jurisdictions in the Amazon operate as a global supplier of key agricultural products. To illustrate, Brazil is as number one producer of soybeans worldwide with a production of 120 million metric tonnes of soybeans each year[111]. Disruptions at the beginning of the supply chain – such as a decline in the production of soybeans – may consequently result in fluctuations of commodity prices on a global level. Those fluctuations could also increase the price for products made from soybeans (animal feed, food, oil, biodiesel etc.).

107 Butler R. A., *The Amazon Rainforest: The World's Largest Rainforest,* Mongabay, June 2020.

108 Ritchie, H., *Is our appetite for soy driving deforestation in the Amazon*, Our World In Data, February 2021.

109 For more details, see the NGFS Technical Document – *Recommendations toward the development of scenarios for assessing nature-related economic and financial risks*, NGFS, December 2023.

110 Khan, Y., *Commodities Come Under Pressure as Macro Headwinds Build*, The Wall Street Journal, October 2023.

111 Marin, F. R., *et al.* (2022) *Protecting the Amazon Forest and reducing global warming via agricultural intensification*, Nature Sustainability.

Macroeconomic deterioration might also occur via a loss of productivity and decreases in employment levels. For example, forest degradation in the Amazon is expected to decrease agricultural productivity. Productivity losses and associated revenues under an adverse deforestation scenario could amount to USD 5.6 billion for soy and USD 180.8 billion for beef by 2050 in net present values[112]. Around 10% of Brazil's employment is in the agriculture sector, highlighting the potential for job losses[113]. Effects on productivity might also occur via incidences of extreme drought in the Amazon. These have disrupted the transportation of products along the Amazon River and disrupted electricity transmission[114]. Moreover, the degradation of the Amazon impacts the provision of food and clean water for local and indigenous people, affecting their health and productivity[115].

Deterioration at the macroeconomic level could result in feedback loops to the microeconomic level, further impacting households and businesses. For example, timber supply may become constrained by consumer demand to source timber from sustainable, certifiable supplies and increased deforestation regulation. This supply constraint can occur simultaneously with an increase in timber consumption due to a rising demand for timber in construction, manufacturing and energy production[116]. A resulting increase in timber prices will subsequently impact the price of housing and certain consumer goods, affecting economic actors at the micro level.

Q2.3 Vulnerability, adaptation and substitution

The vulnerability of at-risk economic actors will largely depend on their ability to adapt. For agriculture, energy and transportation sectors, technological and geographical substitution possibilities may be able to mitigate some of the effects of Amazon degradation and related policies. However, the ability to do so remains subject to high levels of uncertainty. Within the Amazon, some agricultural producers begin to pivot towards more sustainable methods such as agroforestry (a method of growing food and other goods by mimicking natural ecosystems) to rehabilitate parcels of degraded agricultural land[117]. Furthermore, the development and application of new technologies in agriculture is opening up possibilities for new production processes. Technologies are also being developed to increase livestock productivity without increasing deforestation[118]. The transition of the energy grid towards renewable electric power, along with the adoption of second and third-generation biofuels that do not depend on edible plants as their feedstock, may enhance the resilience of the energy grid. Further, waterway transport with hybrid fossil fuel-electric engines could reduce the need to clear forest for new roads[119].

112 Leite-Filho, A. T., *et al.* (2021) *Deforestation reduces rainfall and agricultural revenues in the Brazilian Amazon*, Nature Communications.

113 *Data Bank, World Development Indicators*, The World Bank. For the data mentioned, the series selected was Employment in agriculture (% of total employment) (modelled ILO estimate).

114 For example, in 2023, low river flows from extreme drought resulted in the suspension of a major power transmission line. Due to this, many electrical power plants were unable to connect to the national interconnected system (SIN), thereby disrupting business operations. Low river levels also create problems for transporting the products of small farmers who live on the banks of the large rivers.

115 *New Economy for the Brazilian Amazon*, World Resources Institute, June 2023.

116 *Global forest sector outlook 2050, Assessing future demand and sources of timber for a sustainable economy*. Food and Agriculture Organization of the United Nations, 2022.

117 Nugent, C. *Farming Destroys Brazil's Rain Forests. It could Also Save Them*. Time, January 2023.

118 Filho, F. L. L., Bragança, A. and Assunção, J., *Increasing Cattle Productivity in the Amazon Requires New Technologies*, Climate Policy Initiative, June 2022.

119 *New Economy for the Brazilian Amazon*, World Resources Institute, June 2023.

The substitution possibilities for dependent sectors become more limited or even chronically impaired as the size of the shock or hazard increases. Recent studies have shown that by compounded climatological effects, the rainforest is losing resilience. This can increase the frequency or size of shocks[120]. As the forest continues to degrade, the effectiveness of substitution methods may therefore decline, and risks may compound via complementary and interconnected ecosystem services[121]. To illustrate, farmers may not be able to adapt quickly enough to mitigate impacts from severe drought shocks. This was visible between June 2021 and June 2022 when a severe drought decreased Brazil's national agribusiness earnings by 5.5% compared to the previous year[122]. This drought also resulted in significant losses to the insurance industry[123].

The extent to which operations further down the value chain can substitute geographically might also be restricted by the widespread global degradation of tropical forests and an increase of policy action to protect these vulnerable ecosystems. Southeast Asia is home to nearly 15% of the world's tropical forests and is losing at least 1.2% of its forests annually due to palm oil production, logging, and agriculture[124]. Similarly, according to the UN Food and Agriculture Organization, nearly 4 million hectares of African tropical forests are lost each year[125]. These developments restrict the ability to rely on the necessary ecosystem services in other locations.

Phase 3: Assess risk to, from and within the financial system

Summary of phase 3

This phase illustrates the transmission of economic risks stemming from the Amazon's degradation to the financial sector. The assessment points towards some of the traditional risks categories that may be affected as a result of, among other things: (i) heightened operational risks due to natural hazards; (ii) increased business risks as degraded soil quality prevents the cultivation of certain crops; and (iii) market risks due to fluctuations in commodity prices. The assessment also illustrates how systemic risks may occur, for instance as a result of concentrated exposures to high-impact sectors. By financing high impact activities, such as beef and soy production, the financial sector affects the degradation of the Amazon and the risks that stem from this.

Q3.1 Transmission

The economic risks stemming from the degradation of the Amazon can transmit to the financial system via traditional financial risk categories. For example, recent research by the World Bank explores how banks can be exposed to the loss of biodiversity through their lending activities. It shows that 46% of Brazilian banks' corporate loan portfolio is concentrated in sectors dependent on ecosystem services flowing from the Amazon. Furthermore, losses from ecosystem service collapse could translate to a 9 percentage point increase in corporate non-performing loans[126]. The table below provides examples of how the Amazon's degradation could affect strategic/business model, credit, market and operational risks.

120 *Most Protected areas in Tridom vulnerable to climate change*, WWF, May 2020.

121 For example, soil fertility and nutrient cycling are closely interconnected. Forests contribute to soil fertility by cycling nutrients through the decomposition of organic matter. This nutrient cycling supports plant growth and productivity, which in turn enhances the health and resilience of forest ecosystems.

122 *GDP grows 1.2% in the 2nd quarter of 2022*, Instituto Brasileiro de Geografia e Estatistica, September 2022.

123 Caswell, G. *Drought poses increasing risk for Brazil's financial system*, Green Central Banking, December 2022.

124 Felbab-Brown, V., *The Jagged Edge: Illegal Logging in Southeast Asia*, Brookings, April 2013.

125 *Boosting transparency of forest data, Deforestation continues globally, if at a slower pace*. Food and Agriculture of the United Nations, June 2020.

126 Calice, P., Kalan, F. D. & Miguel, F. (2021) *Nature-Related Financial Risks in Brazil*, The World Bank.

Strategic and Business Model Risk	Credit Risk	Market Risk	Operational Risk
Effects on the availability of high-quality land could force producers to make long term adjustments to their business model.	Decrease in credit worthiness of sectors dependent on the forest which suffer from income losses.	Concentrated financial stress to firms vulnerable from forest degradation leads to asset repricing and market volatility.	An increase in the frequency of natural hazard events disrupts business activity. Risk increases as a result of litigation.
Examples			
Degraded soil quality decreases productivity of agricultural land. Cattle ranchers need to adopt new technologies and management practices to increase pasture productivity.	Reduced agriculture productivity affects the incomes of debtors along the supply chain. For FIs, these clients may be unable to continue to service debt obligations in full and on time.	Severe stress from concentrated agriculture exposure could create the fire sale of assets to raise liquidity, thus impacting the valuation of these assets. Severe impacts to production can drive market volatility. Fluctuations in commodity prices can transmit to FIs which offer hedging and trade finance products.	An increase in wildfires in the Brazilian Amazon during high-deforestation years disrupt mining operations and transportation routes. Environmental and human rights activist groups have started to bring claims against financial institutions for providing financial services to companies contributing to Amazon deforestation.

Q3.2 Systemic dimension

The interconnectedness of financial institutions and the concentration of exposures to high-risk sectors can drive risk propagation within the financial system. If a few financial institutions experience severe stress from concentrated exposures (e.g., to agriculture), then this could create the fire sale of assets that impacts the valuation of these assets (which may cascade to other businesses in the value chain). Any reactionary response in the event of stress could more easily propagate risk across the financial sectors if the largest exposures to high-risk sectors are found in highly connected financial institutions[127].

There may also be contagion within the financial system as actors respond to physical risk. For example, after a number of major wildfires in the Amazon in 2020, a group of investors holding over USD 5 billion in investments threatened to divest from Brazil if sustainability standards were not met[128]. Such actions could change market sentiment, triggering further divestments. Contagion might also occur via litigation risks. Exposure to deforestation activities in the Amazon can result in reputational damage and increased regulatory action against financial institutions providing financing for harmful activities. For example, fines linked to the EU's deforestation law can be as high as 4% of company turnover in an EU Member State[129]. These fines can be a source of risk in itself. But pre-emptive action by investors could amplify risks for all firms that are potentially exposed to such regulatory action.

Amazon degradation may lead to feedback loops between the real economy and the financial sector. For example, if investors adjust their portfolios to compensate for losses in the agricultural sector in the Amazon region, the decrease in investment can create a negative feedback loop where declining investment further diminishes agricultural productivity.

127 A Supervisory Framework for Assessing Nature-related Financial Risks – Identifying and navigating biodiversity risks, OECD, 2023.
128 Spring, J. *Exclusive: European investors threaten Brazil divestment over deforestation*. Reuters, June 2020.
129 *Parliament adopts new law to fight global deforestation*, European Parliament News, April 2023.

Q3.3 Endogenous risk

The financial sector finances activities that contribute to the degradation of the Amazon, thereby amplifying the physical risks to which they or other actors are exposed[130]. The Covid-19 global pandemic is a recent example of this dynamic. Studies indicate that deforestation and land-use conversion, largely driven by agricultural expansion, increase the risk of zoonotic diseases such as Covid-19[131]. It illustrates how nature-related risks can provide widespread economic and financial disruption, impacting the actors that finance risk exacerbating activities[132].

Globally, the forest-risk commodity sectors drive the majority of tropical deforestation. It is estimated that USD 307 billion flows from larger financial institutions into forest-risk commodities[133]. Along commodity supply chains, banks provide a variety of finance and financial services including term loans, trade finance and revolving credit facilities, to bond and fund structuring, capital raising, project finance and more[134]. Within the amazon region, financing provided to the beef and soy sectors in Brazil totalled USD 100 billion from 2013 to April 2020[135]. Although 74% of this total originated from domestic banks, foreign financial institutions also invested in beef, soy and timber production that contributes to the Amazon's deforestation[136]. By financing activities that contribute to the degradation of forests, it is argued that large financial institutions also affect climate stability[137].

130 Pavoni., S, *Banks can offer Amazon rainforest shelter from the storm*, The Banker, March 2021.

131 Dobson, A. P., *et al.* (2020) *Ecology and economics for pandemic prevention*, Science.

132 Calice, P., Kalan, F. D., & Miguel, F. (2021) *Nature-Related Financial Risks in Brazil*, The World Bank.

133 *Banking on Biodiversity collapse, Tracking the Banks and Investors Driving Tropical Forest Destruction*, Forests and Finance, December 2023.

134 *Banking Beyond Deforestation: How the banking industry can help halt and reverse deforestation*, University of Cambridge Institute for Sustainability Leadership, January 2021.

135 *Domestic Banks Finance 74% of Brazilian Beef & Soy*, Chain Reaction Research, December 2020.

136 Ashford, M. and Branford, S., *Foreign capital powers Brazil's meatpackers and helps deforest the Amazon*, Mongabay.

137 Galaz, V., *et al.* (2018) *Finance and the Earth system – Exploring the links between financial actors and non-linear changes in the climate system*, Global Environmental Change.

Phase 1

Identify sources of physical and transition risks

1. Current exposures

- Over 40 million people depend on the Colorado River Basin for their drinking water
- The Basin provides a wide range of provisioning (water and food), regulating (flood control), cultural and supporting services
- Economic actors impact the area by risking its water quality and quantity

2. Priorities

- Agricultural and hydroelectric power sectors have significant impacts and dependencies on the Basin
- The Basin plays a role in the regional and global hydrological cycle, influencing other ecosystems connected to global water circulation and alteration in rainfall patterns.

3. Forward-looking view

- Escalating droughts may lead to physical risks, such as water availability, electricity generation and agricultural limitations
- Firms or assets are exposed to transition risks when local governments change policies and legal frameworks

4. Climate-nature nexus

- Climate change intensifies nature-related financial risks and can negatively affect the quality and quantity of freshwater
- Adaptation and mitigation efforts may unintentionally worsen ecosystem degradation

Phase 2

Assess economic risks

1. Value Chains

- Droughts in the area impact agriculture, energy production, and employment and lead to increased inequality and relocation of economic actors
- Alternatives to hydropower require substantial investments in alternative energy sources creating opportunities and costs

2. Micro-macro interaction

- At the micro level, reduced provision of freshwater affects businesses and households notably through disruptions in economic activities and rising prices
- At the sectoral/regional and macro level the impact could materialize through a decline in value added, socio-economic changes and employment loss

3. Vulnerability and substitution

- Economic actors remain vulnerable given the limited technological and geographical substitution options for freshwater
- (Limited) technological substitution options include changes in agricultural practices and a potential switch to alternative sources of energy

Phase 3

Assess risk to, from and within the financial system

1. Transmissions

- Economic risks can transmit to traditional risk categories for financial institutions (credit and business model risk for businesses in water-dependent sectors, market risk linked to price volatility for water supply, legal risk linked to new regulations)

2. Systemic dimension

- Elevated water prices have the potential to impact the financial systems and trigger feedback loops to the real economy through increased commodity price and cost pressures
- Contagion could occur via commodity markets leading to speculation and market manipulation of water prices

3. Endogenous risks

- Financial institutions' funding of harmful economic activities (e.g., water-intensive agriculture) will aggravate financial risks
- Positive impacts are achievable via financing of sustainable business practices and necessary transitions (e.g., investments in sustainable agricultural practices and technologies)

Freshwater Illustrative Case: the Colorado River Basin

Freshwater ecosystems provide ecosystem services that are critical to many economies. Despite covering less than 1% of the world's total surface area, freshwater ecosystems contain diverse lifeforms housing 10% of all known animals and 40% of all known fish species[138]. At the same time, freshwater ecosystems are habitats that have experienced the sharpest biodiversity decline[139].

One example of such a waterbody is the Colorado River Basin (the "Colorado Basin"). Joined by over 25 significant tributaries (river branches), the Colorado Basin stretches for more than 2,300 kilometres from the central Rocky Mountains in the United States across the Colorado Plateau to Lake Mead before turning south into Mexico and emptying into the Gulf of California. Its waters sustain ecosystems and foster biodiversity. In particular, the basin provides roughly 40 million people across the United States and Mexico with drinking water[140]. The Colorado River, which is part of the Colorado Basin, constitutes a vital water source for agriculture, hydropower generation, municipalities and industries across the United States and Mexico. By walking through the phases in the risk assessment framework, the following sections illustrate how the degradation of the Colorado Basin could result in economic and financial risks.

Phase 1: Identifying sources of nature-related financial risk

Summary of phase 1

This phase seeks to identify the key sources of risks that stem from the degradation of the Colorado Basin. Using the degradation of the Colorado Basin as starting point, this analysis traces backward to identify ecosystem services and sectors most affected by this physical hazard, leveraging tools such as the ENCORE database and WWF risk filters. It also highlights forward looking developments that could amplify or reduce the relevance of these sources of risks. Among other things, the analysis indicates a particular dependency on freshwater provision for municipal, industrial and commercial purposes and on cultural services such as recreation in national parks. High impact and dependency sectors include agriculture and utilities.

Q1.1 Current exposures

The Colorado Basin provides a number of ecosystem services on which economic actors depend. For instance, it provides food, erosion control, natural disturbance regulation as well as recreational services[141]. The Colorado River is also used to generate hydroelectric power[142]. Key ecosystem services currently provided by the Colorado Basin include the below (for further information on impacts and dependencies on water, see also Annex 4)[143]:

- **Provisioning services:** Supply of food, provision of freshwater for agricultural irrigation, provision of freshwater for industrial processes and hydropower, provision of drinking water in U.S. states and northern Mexico.

138 *Freshwater Biodiversity,* WWF, webpage retrieved from: https://wwf.panda.org/.

139 *Living Planet Report 2022 Building A Nature-Positive Society,* WWF, 2022.

140 *A Breakthrough Deal to Keep the Colorado River From Going Dry, for Now,* The New York Times, May 2023.

141 Kaval, P., (2011) *Ecosystem Service Valuation of the Colorado River Basin: A Literature Review and Assessment of the Total Economic Value of the Colorado River Basin,* Conservation Gateway, The Nature Conservatory.

142 James, T., *et al.* (2014) *The Economic Importance of the Colorado River to the Basin Region,* The L. William Seidman Research Institute.

143 References include James, T., *et al.* (2014). *The Economic Importance of the Colorado River to the Basin Region*, A Report by the Arizona State University, and Betley, E. C. (2015), How the West Was Watered: A Case Study of the Colorado River, Center for Biodiversity and Conservation, American Museum of Natural History, USA.

- **Regulating services:** Water purification, flood control, detoxification and natural disturbance regulation.
- **Cultural services:** Spiritual significance, scenic beauty and recreational opportunities, tourism and leisure activities such as sport fishing.
- **Supporting services:** Habitat provision[144], nutrient cycling, water filtration and soil formation[145].

Aside from dependencies, economic actors also impact the Colorado Basin, primarily though water use and pollution. Generally, impacts on freshwater ecosystems can affect two dimensions: water quantity and water quality. Key drivers of negative impacts include land use change (e.g., infrastructure development), overexploitation of water stemming from increased demand, pollution and climate change. To illustrate, sectoral water withdrawals and wastewater generation (particularly due to agricultural, industrial and urban run-offs) can pollute water and jeopardizes water quality[146]. Water shortages, whether due to changing weather patterns or increased demand, amplify these effects as they increase the concentration of pollutants. Such water shortages also occur in the Colorado Basin. To illustrate, the Basin has lost around 40 trillion litres of water due to climate change between 2000 and 2021[147]. This is the equivalent of roughly 33 years of cumulative water usage for the entire population of the United States[148]. Intensive water consumption in the mid-twentieth century has dried the lower 160 km of the Colorado River, meaning the river no longer reaches the sea except in years of heavy run-off[149].

Q1.2 Priorities

Based on the literature studied, the sectors with the largest dependencies and impacts on the Colorado Basin are the agricultural sector (irrigation and livestock) and the hydroelectric power sector (dams along the river)[150]. Of the 7.2 trillion litres of water consumed in a typical year from the Colorado River in the United States, 79% goes to agriculture, 12% to residential use, 4% to commercial and industrial uses and 4% to thermoelectric power[151].

The agriculture and hydroelectric power sectors interact with ecosystems at local, regional and global levels. Locally, the Colorado Basin is directly impacted by these sectors, affecting the river, its tributaries, and surrounding areas crucial for erosion control, natural disturbance regulation and recreational services[152]. For instance, urban ecosystems in seven U.S. states and two Mexican states are connected to the Colorado River, highlighting the direct impact of the loss of ecosystem services on these local communities. Regionally, the effects extend to broader ecosystems influenced by the river's water flow, impacting wildlife and vegetation[153]. The Colorado Basin also plays a role in the regional and global hydrological cycle, influencing other ecosystems that are affected by alterations in rainfall patterns and other changes in global water circulation.

144 Various endangered species use the Colorado River Delta as their habitat for all or part of the year. Betley, E. C. (2015) *How the West Was Watered: A Case Study of the Colorado River,* Network of Conservation Educators and Practitioners, American Natural History Museum.

145 Soil formation is essential for the health of terrestrial ecosystems. Soil is formed by micro-organisms and physical processes that decompose organic matter to small particles. *Ecosystem Services,* EcoShape.

146 DiFelice, M., *The Root of the Colorado River Crisis: Corporate Water Abuse*, Food & Water Watch, February 2023.

147 Bass, B., *et al.* (2023) *Aridification of Colorado River Basin's Snowpack Regions Has Driven Water Losses Despite Ameliorating Effects of Vegetation,* Water Resources Research.

148 The total U.S. water use was roughly 322 billion gallons (1.219 trillion liters) per year in 2015. See: Nastu, J., *Why Overall Water Use Is Declining in US Despite Population Growth,* Environment + Energy Leader, January 2019. At this rate, it would take approximately 33 years of cumulative U.S. water usage to reach the threshold of 40 trillion liters (own calculations).

149 James, T., *et al.* (2014) *The Economic Importance of the Colorado River to the Basin Region,* The L. William Seidman Research Institute.

150 Ibid.

151 I Shao, E. *The Colorado River Is Shrinking. See What's Using All the Water,* The New York Times, May 2023.

152 Kaval, P. (2011) *Ecosystem Service Valuation of the Colorado River Basin: A Literature Review and Assessment of the Total Economic Value of the Colorado River Basin,* Conservation Gateway, The Nature Conservatory.

153 *Two Decades of Changes in Vegetation Greenness and Water Use in the Colorado River Delta,* U.S. Department of the Interior, 2020.

Q1.3 Forward looking view

The escalating frequency of droughts in the Colorado Basin may increase physical risks over time. Research predicts a climate-change induced decline of between 19% to 31% in the Colorado River's flow by 2050 in a worst-case scenario[154]. The historically low reservoir levels can contribute to decreased electricity generation[155], potentially increasing energy prices. The reduced availability of water can also affect water accessibility and prices. Notably, the Colorado River supports around 5.5 million acres of irrigated agriculture[156]. This sector would face risks when water scarcity increases, potentially resulting in the use of public funds to pay farmers to leave land fallow[157]. It could also increase reliance on groundwater, which is itself declining, or increase demands placed on alternative sources of freshwater[158]. The rapid growth of unconventional oil and gas explorations may contribute to water scarcity as it can result in further contamination of the water table. Hydraulically fractured wells are being operated in regions of high to extremely high water stress in Colorado, Texas, Oklahoma and California[159].

Transition risks related to the Colorado Basin are emerging, affecting firms or assets through changes in policy and markets. The U.S. government is addressing persistent ecological risks in the Colorado Basin resulting from climate change and drought. This process, which aims to protect hydropower, water storage and conservation, could affect operating guidelines for the Glen Canyon and Hoover Dams[160]. Also, funding has been made available for infrastructure projects, covering purification, reuse, storage, conveyance, desalination and dam safety[161]. These actions to address water use may require economic actors to reduce freshwater usage. To illustrate, an agreement among lower-basin states was signed in 2023 that commits these states to actively reduce water usage by 13% through the end of 2026[162].

Q1.4 Climate-nature nexus

Freshwater ecosystems are strongly affected by climate change and efforts to combat it. In the Colorado Basin, climate change is a key driver that increases nature-related financial risks. Specifically, climate change contributes to the risks of droughts in the region, affecting both the quantity and quality of available freshwater. At the same time, the degradation of ecosystems increases the economic impacts of climate change through, among other things, soil erosion, reduced groundwater infiltration and the increase of runoff in the Colorado Basin. To combat climate and broader nature-related financial risks at the same time, nature-based solutions are being deployed. Examples include the preservation of riparian zones, wetland conservation and the use of regenerative agriculture. But measures to combat climate change can also amplify nature-related financial risks. For the Colorado Basin, key examples of this include disruption of water flows and river continuity due to hydropower dams or the diversion of waterflows for agricultural irrigation, including crops[163]. The table below provides further detail on these connections.

154 Milly, P. C. D. and Dunne, K. A. (2020) *Colorado River flow dwindles as warming-driven loss of reflective snow energizes evaporation,* Science.

155 Capehart, M. A. (2015) *Drought Diminishes Hydropower Capacity in Western U.S.,* The University of Arizona Water Resources Research Centre.

156 *Colorado River Basin Water Supply and Demand Study Executive Summary*, U.S. Department of the Interior, Bureau of Reclamation, 2012.

157 Bittle, J. *At last, states reach a Colorado River deal: Pay farmers not to farm,* Grist, May 2023.

158 Naishadham, S. *EXPLAINER: How cities in the West have water amid drought,* AP News, May 2022.

159 *Hydraulic Fracturing & Water Stress: Water Demand by the Numbers,* Ceres, February 2016.

160 *Interior Department Announces Next Steps to Protect the Stability and Sustainability of Colorado River Basin,* U.S. Department of the Interior, April 2023.

161 Ibid.

162 *Biden-Harris Administration Announces Historic Consensus System Conservation Proposal to Protect the Colorado River Basin,* U.S. Department of the Interior, May 2023; Trotta, D., and Brooks, B., *Western states reach 'historic' deal to help save Colorado River,* Reuters, May 2023.

163 *Colorado River,* Water Education Foundation; Tidwell, V. C., Malczynski, L. A., & Sun, A. C. T. (2011) *Biofuel impacts on water,* U.S. Department of Energy Office of Scientific and Technical Information.

Connection	Description
Climate change as a driver of nature risk	• Climate change heightens the likelihood of droughts, floods and invasive species through global warming, reduced snowpack, altered precipitation patterns and extreme weather events.
Nature degradation as a driver of climate risk	• Deforestation near watersheds boosts runoff and sedimentation in water bodies. • Urbanization and infrastructure create more impervious surfaces and reduces groundwater infiltration. • Intensive agriculture alters the Colorado River's ecological balance and decreases groundwater availability, amplifying the effects of droughts.
Climate change mitigation and adaptation as a potential driver of nature risk	• Hydropower, expanded biofuel monoculture farming, reservoirs and flood control measures can cause sediment trapping, alter water temperatures and reduce nutrient cycling. • Dams and water diversions disrupt river flows and continuity, causing habitat fragmentation and altering water temperatures.
Nature as a solution to decrease climate risk	• Preservation of riparian zones with native vegetation stabilizes banks, curbs erosion and filters runoff pollutants. • Wetland conservation helps to maintain the hydrological balance.

Phase 2: Assessing economic risks

Summary of phase 2

This phase highlights some of the potential economic risks stemming from the degradation of the Colorado Basin. The assessment indicates that local economic effects for businesses are particularly felt in the agriculture, energy and tourism sectors. These economic effects could cascade through value chains and transmit to other sectors via increased food, water and energy prices. The assessment also identifies potential macro-economic risks, including reductions in agricultural productivity, increased commodity prices and increased fiscal spending on mitigating and transition measures. Potential direct effects on households and communities adds to these risks. The loss of drinking water and recreational opportunities could reduce productivity, affect the health of local populations and trigger conflicts over water rights. The use of technology and changes in production processes facilitate substitution and reduce vulnerability to the degradation of the Colorado basin. However, substitution possibilities for freshwater are limited and may not be implemented rapidly enough to offset short term water shortages.

Q2.1 Value chains

Droughts in the Colorado Basin have triggered direct, mostly local, economic effects that particularly impact food production. The region's reliance on the Colorado Basin for agriculture, irrigation and general employment exacerbates the threat to food production and labour income as overuse and diminishing water resources significantly strain the agricultural sector[164]. The Colorado Basin supports an estimated USD 8 billion direct annual income from agriculture. Specifically, it supports 90% of the region's winter vegetables, sustains cattle and dairy operations throughout the western US and supports around 175,000 acres of cotton cultivation in Arizona[165].

Decreased water flow also hampers the generation of hydropower, affecting energy production for households and industries[166]. For instance, in 2021, hydropower facilities at the Nevada-Arizona border have more than 4,200 megawatts of electricity generating capacity. Approximately half of this capacity is located at the Hoover Dam, generating electricity for roughly 1.3 million residents[167]. Short-term projections show that an annual 0.5% to 2.5% drop in hydropower generation from the Hoover Dam can be expected because of a decrease in water flow[168]. As the demand for electricity continues to grow,

164 Christianson, M. (2024) *Eternal Options: How Farmers and Ranchers Are Innovating in Response to a Shrinking Colorado River,* Environmental and Energy Study Institute.

165 De Souza, K., *et al.* (2020) *Scaling Corporate Water Stewardship to Address Water Challenges in the Colorado River Basin,* The Pacific Institute.

166 Gilbert, L., *Research from USU's Centre of Colorado River Studies Cited in U.S. President's Report on Economy*, Utah State University, Utah State Today, March 2023.

167 Ramirez, R,. *The West's historic drought is threatening hydropower at Hoover Dam*, CNN, August 2022.

168 Calimlim Touton, C. (2022) *Hydropower Opportunities and Challenges*, Statement to U.S. Senate Committee of Energy and Natural Resources, U.S. Department of the Interior.

reduced hydropower generation due to droughts poses challenges to maintaining a stable supply or electricity for economic actors in the region.

More generally, the Colorado Basin helps support around 16 million jobs and USD 942 billion labour income annually that could be affected by water stress[169]. Aise from water stress, local communities and tribes may also be affected by the loss of flora and fauna. The Colorado River flows through seven national wildlife refuges and 11 National Park Service units, the loss of which could affect tourism and recreational opportunities[170].

Prolonged droughts in the Colorado Basin also have the potential to result in indirect economic effects, including through food and energy value chains. Local economic dislocation has risen as diminished water resources force agricultural businesses to downsize or cease operations. This results in job losses and other social challenges such as increased inequality, especially in rural communities[171]. Simultaneously, increased water costs have cascaded across sectors impacting both businesses and households. As the region navigates an energy transition away from hydropower due to expected water scarcity, substantial investments in alternative energy sources like solar, wind and nuclear power may be required[172]. This presents both opportunities and costs for associated industries and service providers[173].

Multi-Regional Input-Output (MRIO) tables may be used to assess such indirect economic effects. For example, in the NGFS Technical Document on Nature Scenarios, a Multi-Regional Input-Output (MRIO) table is used to quantify such indirect economic effects for a case study on a potential drought in France[174]. The results of this case study indicate that 14% of the agricultural output in France would be impacted from shortages in water supply. Other sectors impacted include mining, manufacturing, electricity and utilities and transport.

Q2.2 Micro-macro interaction

The response to Q2.1 above illustrate how the reduced provision of freshwater directly and indirectly affects households and businesses. On a micro level, these effects manifest through: (i) disruptions in productions' processes in certain sectors; (ii) adjustments in economic activities; (iii) changing price levels; and (iv) the pricing of externalities. For example, a reduced production of hydroelectricity is already observed. Water levels in Lake Mead, one of the largest reservoirs, has been at around 25% of its capacity[175]. This increases the risk of price increases for utilities (water and electricity). Furthermore, the power sector is considering adjusting its economic activities towards building infrastructure for solar and wind energy. Aside from being a risk to affected businesses, such changes in economic activity may also amplify economic risks via an increase of physical risks when the new economic activity have negative effects on nature (e.g., when the installation of solar panels results in habitat loss for birds).

The direct economic effects also extend to the sector/regional and macro level. In the case of the United States, around 64% of the Basin region's annual gross state product could be lost if the Colorado river is no longer available to the residents, businesses, industrial and agricultural sectors[176]. Direct losses are estimated at around USD 695 billion and indirect losses at around USD 230 billion[177]. For Mexico, the direct effects on GDP are likely more limited (the Colorado Basin only contributes roughly 3% to the GDP of the Baja Norte Province)[178]. But similar to the United States, communities reliant on the Colorado River

169 James, T., *et al.* (2014) *The Economic Importance of the Colorado River to the Basin Region,* The L. William Seidman Research Institute.

170 *Management of the Colorado River: Water Allocations, Drought, and the Federal Role,* Congressional Research Services, April 2014.

171 Christianson, M., (2024) *Eternal Options: How Farmers and Ranchers Are Innovating in Response to a Shrinking Colorado River,* Environmental and Energy Study Institute.

172 Ibid.

173 Smith, J. *Electric costs in Colorado set to surge as Lake Powell struggles to produce hydropower*, Water Education Colorado, September 2021.

174 *Recommendations toward the development of scenarios for assessing nature-related economic and financial risks*, NGFS, December 2023.

175 Milman, O., *Severe drought threatens Hoover dam reservoir – and water for US west,* The Guardian, July 2021.

176 James, T., *et al.* (2014) *The Economic Importance of the Colorado River to the Basin Region,* The L. William Seidman Research Institute.

177 Both in 2014 USD. See: James, T., *et al.* (2014) *The Economic Importance of the Colorado River to the Basin Region,* The L. William Seidman Research Institute.

178 *The U.S., Mexico and The Decline Of The Colorado River, Fobes*, May 2013.

are impacted by its degradation[179]. At the macro level, the impact could therefore be visible through a decline in gross state product and employment loss. A reduction in the provision of freshwater could also result in socio-economic changes. The increase in fallow lands has also led to a rise in valley fever, posing significant hazards to human health[180]. Moreover, dwindling groundwater and shrinking Colorado River has led the state of Arizona to limit housing construction in the Phoenix area. That could also price risks for the real estate market in the region going forward[181]. Competition over water rights may result in conflicts between countries, regions and communities[182].

Q2.3 Vulnerability, adaptation and substitution

There are some options to adapt to the consequences of the negative impacts to the Colorado Basin. For instance, businesses might be able to change their production processes or location to rely less on the provision of freshwater from the Colorado Basin (geographical substitution). One example of this is the transformation of agricultural practices. To illustrate, forage crops and particularly alfalfa are part of a larger food system that includes beef and dairy industries. These livestock feed crops make up 70% of all the river water used for irrigation[183]. To adjust to a reduced supply of freshwater, farmers may decide to substitute alfalfa with less water-intensive crops, or by planting a forage-mix of wheat, barley, oats, rye and peas[184]. State-directed substitution possibilities at the residential level, such as replacing lawns with drought-resistant landscaping, can also limit water usage. Another substitution example is the potential switch from hydropower to alternate sources of energy such as solar power[185]. Certain technologies such as water-saving irrigation practices may also reduce water consumption by economic actors in the region (technological substitution).

Geographic and technological substitution might help to mitigate the risks, but will not be able to fully eliminate the dependency of economic actors on freshwater provision by the Colorado Basin. Economic actors will therefore remain vulnerable given the limited substitution options for freshwater. To illustrate, local residents will continue to rely on the basin for essential needs such as drinking water and cultural services. And although geographical substitution via the import of bottled drinking water could be applied, this would likely increase water prices in the medium to long run. This highlights the importance of clean water as a critical ecosystem service which is difficult to substitute completely. Furthermore, although operational solar projects do not depend on water, their construction does requires water for dust mitigation. That construction has resulted in the drying of local wells, groundwater table depletion and over-drafting of aquifers in California's Colorado Desert[186].

179 Kohli, A. *Colorado River Drought Crisis is Fostering a More Collaborative U.S.-Mexico Relationship,* Time Magazine, May 2023.

180 *Faller, M.B., The future of water in Arizona*, Arizona State University News, November 2022.

181 Flavelle, C., and Healy, J., *Arizona Limits Construction Around Phoenix as Its Water Supply Dwindles*, The New York Times, June 2023.

182 Cohen, M., and Gleick, P. H., *How to Save the Colorado River and the American West*, Time Magazine, January 2023.

183 *Big Ag is Draining the Colorado River Dry,* Food & Water Watch, August 2023.

184 Fu, J., *It's the thirstiest crop in the US south-west. Will the drought put alfalfa farmers out of business?* The Guardian, September 2022.

185 Some of the states and Tribes have accepted water supply cuts to their allocations. A survey by the American Farm Bureau Federation of more than 650 farmers in 15 Western States indicated that persistent drought-like conditions in the Basin area led to a 74% reduction in harvests and 42% switched crops. In Arizona, 40% of the survey respondents stated that they removed orchard trees or other multi-year crops owing to water supply restrictions. Wheat, corn, berries, and fresh produce are likely to be particularly strained by supply rationing to manage water-stress. Munch, D., *New AFBF Survey Shows Drought's Increasing Toll on Farmers and Ranchers*, Farm Bureau, August 2022.

186 Myskow, W., *Solar Is Booming in the California Desert, if Water Issues Don't Get in the Way,* Inside Climate News, June 2023.

Phase 3: Assess risks to, from and within the financial system

Summary of phase 3

This phase demonstrates how the identified economic risks could result in financial risks. The assessment illustrates how the degradation of the Colorado Basin could increase credit risk due to increased probabilities of default. It can also heighten market risk due to commodity price fluctuations, affect business model risks as economic activities in the region change and impact operational risks due to water-related litigation. Those risks could spread across the financial system, including via water futures markets. The financing of economic activities with high negative impacts – including water-intensive forms of agriculture and unsustainable tourism – amplifies the risks to which financial actors may be exposed.

Q3.1 Transmission

The economic risks stemming from the degradation of the Colorado Basin can transmit to the financial system via traditional risk categories for financial institutions. Estimates suggest that the contribution of the finance and insurance sector to the region's gross state product could decline by around USD 137 billion if the Colorado River is unavailable for a year[187]. The table below illustrates how traditional financial risk categories could affect credit risk, market risk, strategic and business model risk and legal risks.

Strategic and Business Model Risk	Credit Risk	Market Risk	Operational Risk
Companies in water-dependant sectors face disruptions in production and distribution, requiring new strategies and investments in mitigation or relocation.	Businesses in water dependent sectors face higher chances of failure due to e.g., reduced crop yields, increased production costs and reduced electricity generation.	Water scarcity increases price volatility for water supply and subsequent products, destabilizes financial markets and investments. It could also drive stranded assets and affect collateral values[4].	Introduction of new regulations related to water resources, leading to compliance issues, legal disputes[6], and reputational damages.
Examples			
New technologies like blockchain and satellites[1], or new irrigation techniques such as sprinklers and laser levelling, improve water management. New turbines enable energy production at lower water levels[2].	Difficulties in loan repayment, meeting financial obligations, downgrading in credit rating[3] and difficulties with accessing new capital.	The electricity price at the Glen Canyon Dam power plant has risen up to USD 1,000 per megawatt hour from USD 30 per megawatt hour in the open market[5].	Lawsuits are filed for neglection of water rights[7].

1 Xiao, M, *et al.* (2022) *On the value of satellite remote sensing to reduce uncertainties of regional simulations of the Colorado River,* Hydrology and Earth System Sciences.
2 Tweed, K. (2013) *Colorado River Hydropower Faces a Dry Future > Drought is hindering output from the river's iconic dams,* IEEE Spectrum.
3 *Public Power Credit Unaffected by Glen Canyon Dam Drought Measures,* Fitch Ratings, May 2022.
4 Myskow, W. and Peterson, E. (2023) *As the Colorado River Declines, Water Scarcity and the Hunt for New Sources Drive up Rates,* Inside Climate News.
5 Arena, A. (2023) *The Colorado River's Urgent Lesson for Energy Policy,* Slate.
6 Runyon, L. (2019) *New Analysis Spells Out Serious Legal Risk To Colorado River Water Users,* KRCC.
7 *Supreme court rules against Navajo nation in Colorado River water dispute,* The Guardian, June 2023.

187 James, T., *et al.* (2014) *The Economic Importance of the Colorado River to the Basin Region,* The L. William Seidman Research Institute.

Q3.2 Systemic dimension

Via increased costs, the adverse impact of water stress in the Colorado River has the potential to affect the broader financial system and potentially cause feedback loops to the real economy. Specifically, the increase in prices could impact multiple businesses simultaneously, leading to heightened credit and market risks across various exposures. This could, in turn, affect numerous financial institutions through their exposures. To illustrate, persistent droughts in the Colorado River have led to increased expenses for alternative sources of energy due to a decline in hydroelectric power generation. Equally, water shortages may impact agricultural businesses and increase food prices as well as prices for commodities such as tomatoes, cotton, corn and cattle feed for businesses further down the value chain[188]. Evidence suggests cattle feed prices rose by 45% due to the severe Colorado drought during 2010-11[189].

Contagion could also occur through commodity markets. The launch of the water futures market in California has led to the increased commodification and privatisation of water, potentially resulting in speculation and market manipulation of water prices with adverse impacts for businesses and financial institutions[190]. Through this futures market, a feedback loop may emerge between the financial market and the real economy. Small farmers would be strongly affected by this as large seller of water rights. High water prices could also render irrigation unaffordable for many small farmers, affecting their profitability and ability to sustain their business[191].

Q3.3 Endogenous risk

Economic activities that negatively impact the Colorado Basin will in part be financed by financial institutions, thereby amplifying nature-related financial risks stemming from the degradation of this ecosystem. This includes, for instance, the financing of water-intensive agriculture (mainly alfalfa, grasses and corn silage for livestock feed), financing of hydropower and investments in unsustainable forms of tourism and leisure (e.g., resorts in vulnerable ecosystems and water-intensive residential amenities such as golf courses)[192]. At the same time, positive impacts may be achieved through the financing of sustainable business practices and necessary transitions (e.g. investments in sustainable agricultural practices and technologies[193], crop diversification and energy source diversification). Examples include the acquisition of water rights for ecological benefits, high-efficiency irrigation on tribal reservations and the restoration of perennial flows to increase groundwater resources[194]. Some financial institutions are covering around 6-10% of the water-saving expenses made by farmers[195].

188 Frandino, N., Walljasper, C., and Guerrucci, A., *California's drought withers tomatoes, pushing grocery prices higher,* Reuters, October 2022.

189 *How Drought Affects Colorado's Agriculture Industry, An economic case study of the 2011-2013 drought*, Colorado Water Conservation Board, May 2020.

190 *The Water Futures Market: Gambling With Our Water*, Food & Water Watch, December 2021.

191 Ibid.

192 Canon, G., *Tourism is sucking Utah dry. Now it faces a choice – growth or survival?*, The Guardian, September 2022.

193 Palmer, J. *Agriculture 3.0: Preparing for a Drier future in the Colorado River Basin,* Eos, July 2023.

194 The 2023 Colorado River Basin Water Scarcity Challenge, where three water management projects were selected to overcome water shortage in the area. The project is coordinated by Quantified Ventures which is offering consulting, project development and financing and funding solutions that can deliver beneficial outcomes for Colorado River Basin ecosystems and its communities – *Three Emerging Water Management Projects Win Colorado River Basin Water Scarcity Challenge,* Quantified Ventures, September 2023.

195 *Colorado River,* Feeding Ourselves Thirsty.

Annexes

Annex 1 – Glossary

Biodiversity: The variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems[196].

Ecosystem services: A range of material and non-material benefits that humans, directly and indirectly, obtain from nature and that sustain and fulfil human life[197].

Ecosystems: A dynamic complex of plant, animal and microorganism communities and the non-living environment, interacting as a functional unit[198].

Natural capital: The stock of renewable and non-renewable natural resources (e.g., plants, animals, air, water, soils, minerals) that combine to yield a flow of benefits to people[199].

Nature: It is difficult to define nature, given that various meanings attached to it depend on the context in which it is used. To illustrate its meaning, reference is made to definition used in the IPBES Conceptual Framework: "The natural world with an emphasis on the diversity of living organisms and their interactions among themselves and with their environment[200]." The key consideration for the purposes of this framework is that the term 'nature' captures both the biotic (living) and abiotic (non-living) elements of our planet, including biodiversity but also climate.

Nature-related financial risk: The risks of negative effects on economies, individual financial institutions and financial systems that result from: (i) the degradation of nature, including its biodiversity, and the loss of ecosystem services that flow from it (i.e., physical risks); or (ii) the misalignment of economic actors with actions aimed at protecting, restoring, and/or reducing negative impacts on nature (i.e., transition risks)[201].

Physical risks: The risk of economic costs and financial losses resulting from the degradation of nature and consequential loss of ecosystem services that economic activity depends upon. Physical risks can be chronic (e.g. a gradual decline of species diversity of pollinators resulting in reduced crop yields, deforestation, or water scarcity) or acute (e.g. an increased probability of new pandemics)[202].

Transition risks: The risk of economic costs and financial losses resulting from the misalignment of economic actors with actions aimed at protecting, restoring, and/or reducing negative impacts on nature. Transition risks can be prompted, for example, by changes in regulation and policy, legal precedent, technology, or investor sentiment and consumer preferences[203].

196 *Convention on Biological Diversity*, 1992, Article 2. This definition is, *inter alia*, also used in: the Final Report, NGFS-INSPIRE Study Group, March 2022; and Glossary (version 1.0), TNFD.

197 The Final Report, NGFS-INSPIRE Study Group, March 2022. Derived from *Ecosystems and human well-being: Biodiversity synthesis*, Millennium Ecosystem Assessment, World Resources Institute, 2005.

198 *Convention on Biological Diversity*, 1992, Article 2. This definition is, *inter alia*, also used in: Glossary (version 1.0), TNFD; and the *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*, IPBES, 2019.

199 *Natural Capital Protocol*, Natural Capital Coalition, 2016. This definition is, *inter alia*, also used in: Final Report, NGFS-INSPIRE Study Group, March 2022; Glossary (version 1.0), TNFD; and the *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*, IPBES, 2019.

200 Díaz, S., *et al.* (2015) *The IPBES Conceptual Framework – connecting nature and people*. This definition is, *inter alia*, also used as working definition in the Glossary (version 1.0), TNFD.

201 This definition covers both "environmental-related risks" and "climate-related risks" as defined in *A call for action – Climate change as a source of financial risk, NGFS*, 2019 (p. 11). Environmental-related risks were defined in that report as: "*risks (credit, market, operational and legal risks, etc.) posed by the exposure of financial firms and/or the financial sector to activities that may potentially cause or be affected by environmental degradation (such as air pollution, water pollution and scarcity of fresh water, land contamination, reduced biodiversity and deforestation)*. Climate-related risks were defined as: "*risks posed by the exposure of financial firms and/or the financial sector to physical or transition risks caused by or related to climate change (such as damage caused by extreme weather events or a decline of asset value in carbon-intensive sectors)*".

202 Adapted from *Guide for Supervisors Integrating climate-related and environmental risks into prudential supervision*, NGFS, 2020; and the Final Report, NGFS-INSPIRE Study Group, March 2022.

203 Ibid.

Annex 2 – Ecosystem services and ecosystems

Table 1 **Overview of commonly used categorisations of ecosystem services**[1]

Millennium Ecosystem Assessment (2005)	IPBES (2018)	ENCORE (2024 version)[2] Based on UN SEEA EA	TNFD (2023) Based on UN SEEA EA
Provisioning services (e.g., food, fresh water)	**Material:** • Food and feed • Materials and assistance • Medicinal, biochemical and genetic resources • Energy	**Provisioning:** • Biomass provisioning services • Genetic material services • Water supply • Other provisioning services: animal-based energy*	**Provisioning:** • Biomass provisioning • Genetic material • Water supply • Other provisioning services
Regulating services (e.g., climate regulation, pollination, water regulation) Supporting services (e.g., soil formation, nutrient cycling)	**Regulating:** • Regulation of air quality • Regulation of climate • Pollination and dispersal of seeds and other propagules • Regulation of freshwater quantity, location and timing • Regulation of freshwater and coastal water quality • Regulation of ocean acidification • Regulation of hazards and extreme events • Regulation of organisms detrimental to humans • Formation, protection and decontamination of soils • Habitat creation and maintenance	**Regulation and maintenance:** • Air filtration services • Local climate regulation services • Global climate regulation services • Pollination services • Water flow regulation services • Flood mitigation services • Storm mitigation services • Rainfall pattern regulation • Water purification services • Biological control services • Solid waste remediation • Soil and sediment retention services • Soil quality regulation services • Nursery population and habitat maintenance services • Noise attenuation services • Other regulating and maintenance services: dilution by atmosphere and ecosystems* • Other regulating and maintenance services: mediation of sensory impacts (other than noise)*	**Regulation and maintenance:** • Air filtration • Local climate regulation • Global climate regulation • Pollination • Water flow regulation • Flood mitigation • Storm mitigation • Rainfall pattern regulation • Water purification • Biological control • Solid waste remediation • Soil and sediment retention • Soil quality regulation • Nursery population and habitat maintenance • Noise attenuation • Other regulating and maintenance services
Cultural services (e.g., recreation, educational and spiritual services)	**Non material:** • Learning and inspiration • Physical and psychological experiences • Supporting identities **Other:** • Maintenance of options	**Cultural:** • Recreation-related services • Visual amenity services • Education, scientific and research services • Spiritual, artistic and symbolic services	**Cultural:** • Recreation-related services • Visual amenity services • Education, scientific and research services • Spiritual, artistic and symbolic services • Other cultural services

1 Input obtained from: Millenium Ecosystem Assessment (2005) *Ecosystems and Human Well-being: Synthesis*; IPBES (2019) *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*, ENCORE Partners (Global Canopy, UNEP FI, and UNEP-WCMC) (2024) *ENCORE: Exploring Natural Capital Opportunities, Risks and Exposure*; TNFD (2023) *Recommendations of the Taskforce on Nature-related Financial Disclosures*.

2 Reflects an updated version of the knowledge base behind the ENCORE tool that will be available in Q3 2024.

* Not separately defined in SEEA EA but retained from the 2018-2023 version of the ENCORE knowledge base for consistency. Definitions are based on the Common International Classification of Ecosystem Services (CICES).

Table 2 **Overview of different commonly used categorisations of ecosystems**[1]

Realms		IUCN Global Ecosystem Typology (v2.1)	TNFD (2023)[2] Based on IUCN GET and UN SEEA	ENCORE (2024 version)[3]
Land	Terrestrial	• Tropical-subtropical forests (T1) • Temperate-boreal forests and woodlands (T2) • Shrublands and shrubby woodlands (T3) • Savannas and grasslands (T4) • Deserts and semi-deserts (T5) • Polar/alpine (cryogenic) (T6) • Intensive land-use (T7)	• Tropical-subtropical forests (T1) • Temperate-boreal forests and woodlands (T2) • Shrublands and shrubby woodlands (T3) • Savannas and grasslands (T4) • Deserts and semi-deserts (T5) • Polar/alpine (T6) • Intensive land-use (T7) • Subterranean cave and rock systems (S1) • Artificial subterranean spaces (S2)	• Tropical-subtropical and Temperate-boreal forests and woodlands (T1 + T2) • Shrublands & shrubby woodlands, Savannas and grasslands (T3 + T4) • Desert and Semi-deserts (T5) • Polar/alpine (T6) • Intensive Land Use Systems (T7): Croplands, pastures and plantations • Intensive Land Use Systems (T7): Urban and industrial ecosystems *See below the 'subterranean ecosystems' type that also includes the land-related subterranean ecosystem types.*
	Subterranean	• Subterranean lithic (S1) • Anthropogenic subterranean voids (S2)		
Ocean (including related transitional realms)	Marine	• Marine shelf (M1) • Pelagic ocean waters (M2) • Deep sea floors (M3) • Anthropogenic marine (M4)	• Marine shelf (M1) • Open ocean waters (M2) • Deep sea floors (M3) • Artificial marine systems (M4) • Subterranean tidal (SM1) • Shoreline systems (MT1) • Maritime vegetation (MT2) • Artificial shorelines (MT3) • Coastal inlets and lagoons (FM1) • Brackish tidal systems (MFT1)	• Marine shelfs (M1) • Pelagic ocean waters and deep sea floors (M2 + M3) • Anthropogenic marine systems (M4) • Shoreline systems (including Anthropogenic shorelines) and supralittoral coastal systems (MT1 + MT2 + MT3) • Semi-confined transitional waters (FM1) • Brackish tidal systems (MFT1) *See below the 'subterranean ecosystems' type that also includes the ocean-related subterranean ecosystem types.*
	Marine – Subterranean	• Subterranean tidal (SM1)		
	Marine – Terrestrial	• Shorelines (MT1) • Supralittoral coastal (MT2) • Anthropogenic shorelines (MT3)		
	Marine – Freshwater	• Semi-confined transitional waters (FM1)		
	Marine – Freshwater – Terrestrial	• Brackish tidal (MFT1)		
Freshwater (including related transitional realms)	Freshwater	• Rivers and streams (F1) • Lakes (F2) • Artificial wetlands (F3)	• Rivers and streams (F1) • Lakes (F2) • Artificial wetlands (F3) • Vegetated wetlands (TF1) • Subterranean freshwaters (SF1) • Artificial subterranean freshwaters (SF2)	• Artificial fresh waters, lakes, rivers and streams (F1 + F2+ F3) • Palustrine wetlands (TF1) *See below the 'subterranean ecosystems' type that also includes the freshwater-related subterranean ecosystem types.*
	Freshwater – Terrestrial	• Palustrine wetlands (TF1)		
	Freshwater – Subterranean	• Subterranean freshwaters (SF1) • Anthropogenic subterranean freshwaters (SF2)		
				• Subterranean ecosystems (S1 + S2 + SM1 + SF1 + SF2)

1 Input obtained from: IUCN (2022) IUCN Global Ecosystem Typology (v2.1); ENCORE Partners (Global Canopy, UNEP FI, and UNEP-WCMC) (2024) *ENCORE: Exploring Natural Capital Opportunities, Risks and Exposure*; TNFD (2023) *Recommendations of the Taskforce on Nature-related Financial Disclosures.*

2 The TNFD also includes 'atmosphere' as one of the realms but does not connect any biomes to that realm.

3 Reflects an updated version of the knowledge base behind the ENCORE tool that will be available in Q3 2024. Coding (e.g. 'T1') has been added in this document to improve comparability.

Annex 3 – Overview of guiding questions

Phase 1: Identify sources of physical and transition risk	Phase 2: Assess economic risks	Phase 3: Assess risk to, from and within the financial system
Q1.1 Current exposures: • Which direct and indirect dependencies does the economy and the financial sector (incl. via insured and financed activities) have on ecosystem services? • Which direct and indirect negative impacts does the economy and the financial sector have on nature? • Which of those dependencies and negative impacts could be material sources of physical and transition risk from a microprudential, macroprudential and/or macroeconomic risk perspective?	**Value chains:** • Where are the direct economic effects located (domestically or abroad)? • Can direct effects transfer across borders and/or amplify (including domestically) through value chains, thereby resulting in indirect economic effects? • Can risks cascade to different value chains?	**Transmission:** • How can economic risks transmit to traditional financial risk categories?
Q1.2 Priorities: • What are the key sectors with the highest impacts and dependencies (both direct and indirect) on nature? • What are the critical global, regional and/or local ecosystems these key sectors, or the economy/financial sector as a whole, interact with, and where are they located? • What is the current or estimated state of these critical ecosystems?	**Micro-macro interaction:** • To what extent do economic effects on households and businesses as a result of nature-related financial risks lead to macroeconomic deterioration, including lower productivity or inflationary pressures? • Are there any risks that directly create effects at the macro level? • Could macroeconomic deterioration affect or create a feedback loop to the micro level?	**Systemic dimension:** • How can nature-related financial risks amplify via feedback loops within the financial sector, or between the financial sector and the real economy?
Q1.3 Forward-looking view: • Are there any future developments that should be considered when assessing sources of physical and transition risks such as emerging policy frameworks or the sudden collapse of one or more ecosystem services? • Over what time horizon are these forward-looking developments expected to materialise?	**Vulnerability, adaptation and substitution:** • How vulnerable are economic actors given their ability to adapt (e.g. via substitution)? • For the identified economic transmission channels, what technological or geographical substitution possibilities are available that could mitigate the effects of shocks and hazards? • How would these possibilities change as the size of the shock or hazard increases?	**Endogenous risk:** • Is the financial sector materially contributing to the physical risks to which it is exposed to?
Q1.4 Climate-nature nexus: • How does the consideration of climate change (and related mitigation/adaptation strategies) affect the identification of potential nature-related financial risk? • Could sectors with large dependencies or impacts on nature be contributing to climate change, or be affected by it? • Which strategies for climate change mitigation have the potential to cause inadvertent negative effects on ecosystems, thereby amplifying nature-related financial risks?		

Annex 4 – Forest and water impact and dependencies

Table illustrating direct dependency, dependency on enabling ecosystems, and impact by several industries for water and forest as natural capital (extracted from Encore and WWF Risk Filter).

Industries	**Dependency (direct):** Surface Water	**Dependency (direct):** Ground Water	**Dependency: (direct)** Forest	**Dependency (enabling):** Soil Quality	**Dependency (enabling):** nursery habitats	**Dependency (enabling):** Waterflow maintenance	**Dependency (enabling):** Water Quality	**Dependency (enabling):** Soil Quality	**Impact:** Forest Ecosystem use	**Impact:** Water Use	**Impact:** Tree Cover	**Impact:** Atmosphere (ecosystem use)
Agriculture (plant products)	■	■	■	■		■	■	■	■	■	■	
Agriculture (animal products)	■	■	■				■			■	■	
Appliances & General Goods Manufacturing										■		
Chemicals & Other Materials Production			■							■		
Construction materials production	■	■	■								■	■
Combustion & Geothermal Energy	■	■	■							■	■	
Hydropower	■					■			■	■	■	■
Solar, Wind										■		
Oil, Gas, Consumable Fuels		■	■						■	■	■	■
Fishing & Aquaculture	■				■		■		■		■	
Food & Beverage Production	■	■	■								■	
Forest Product & Paper Production	■	■	■							■	■	
Forestry	■	■	■			■					■	
Metals & Mining										■	■	
Textiles, Apparel & Luxury Good Production	■	■								■	■	
Transportation									■			
Water Utilities Providers	■	■				■					■	

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