

## A “Silent Spring” for the Financial System? Exploring Biodiversity-Related Financial Risks in France

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### ABSTRACT

This paper contributes to an emerging literature aimed at uncovering the linkages between biodiversity loss and financial instability, by exploring biodiversity-related financial risks (BRFR) in France. We first build on previous studies and propose an analytical framework to understand BRFR, emphasizing the complexity involved and the limited substitutability of natural capital. We then provide quantitative estimates of dependencies and impacts of the French financial system on biodiversity. We find that 42% of the value of securities held by French financial institutions comes from issuers that are highly or very highly dependent on one or more ecosystem services. We also find that the accumulated terrestrial biodiversity footprint of these securities is comparable to the loss of at least 130,000 km<sup>2</sup> of “pristine” nature, which corresponds to the complete artificialization of 24% of the area of metropolitan France. Finally, we suggest avenues for future research through which these estimates could feed into future assessments of physical and transition risks.<sup>2</sup>

**Keywords:** Biodiversity; Financial stability; Environmental risks; Scenario analysis; Financial markets and the macroeconomy; Valuation of ecosystem services.

**JEL classification:** C67, D81, E44, G32, Q51, Q57

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## NON-TECHNICAL SUMMARY

Biodiversity is the living fabric of our planet, yet it is facing a massive decline caused by human activities. The risks posed by biodiversity loss to ecological and socioeconomic systems could be at least as high as those imposed by climate change, in addition to interacting with them. In this context, the financial community recently started paying attention to biodiversity-related financial risks (BRFR): as BRFR could pose a threat to financial stability, it has become increasingly important for central banks and financial supervisors to better understand such risks. However, a wide range of challenges, including the complexity of ecosystem processes and the limited substitutability of ‘natural capital’, makes assessing BRFR even more complex than assessing climate-related financial risks.

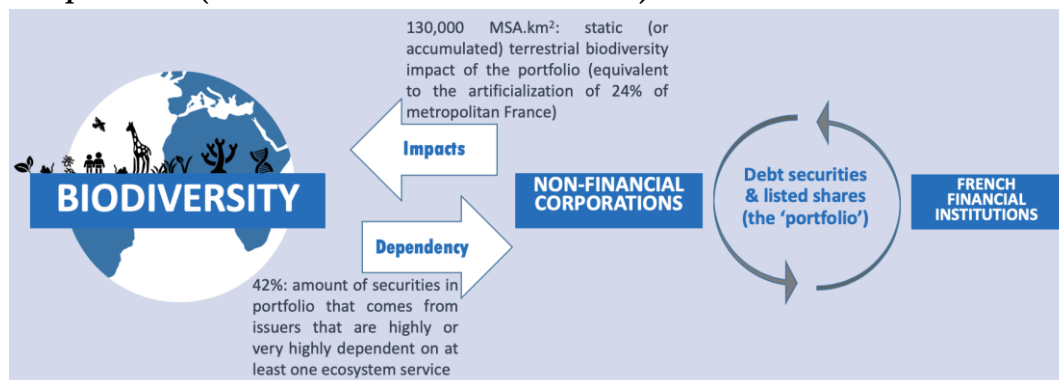
Against this backdrop, we build on van Toor et al.’s (2020) pioneering study in the Netherlands to provide the first exploration of BRFR for the French financial system. Based on data of the debt securities and listed shares issued by non-financial corporations and held by French financial institutions (the ‘portfolio’), we proceed as follows.

To approximate physical risks, we provide a measure of the dependencies of the economic activities financed by French financial institutions to a list of 21 ecosystem services. Considering the direct dependencies: we find that 42% of the market value of securities held by French financial institutions comes from issuers (non-financial corporations) that are highly or very highly dependent on at least one ecosystem service. Considering the upstream (or indirect) dependencies to ecosystem services, we find that all security issuers in the portfolio are at least slightly dependent to all ecosystem services through their value chains.

To approximate transition risks, we provide measures of impacts on terrestrial and freshwater (i.e. not marine) biodiversity of economic activities financed by French financial institutions (i.e. the “biodiversity footprint” of their portfolio). We find that the accumulated (or static) terrestrial biodiversity footprint of the French financial system is comparable to the loss of at least 130,000km<sup>2</sup> of ‘pristine’ nature, which corresponds to the complete artificialization of 24% of the area of metropolitan France. Land use change is the main pressure explaining these results. Moreover, the portfolio of French financial institutions has an annual additional (or dynamic) impact on terrestrial biodiversity that is comparable to the loss of 4,800km<sup>2</sup> of ‘untouched’ nature, corresponding to an annual complete artificialization of 48 times the area of Paris. Climate change is the main pressure explaining these results.

Lastly, we suggest future avenues of research consisting in: (i) developing biodiversity-related scenarios tailored to financial risk assessment; (ii) using specific methodologies that can better capture the limited substitutability of ecosystem services and the nonlinear patterns that their disruption could generate; and (iii) developing new tools through which the alignment of financial institutions with biodiversity-related goals could be assessed.

## Dependencies on ecosystem services and impacts on biodiversity corresponding to the 'portfolio' (debt securities and listed shares) of French financial institutions



Note: The dependency score is obtained through the ENCORE methodology, and it provides insights into the assessment of biodiversity-related physical risks. The biodiversity footprints are obtained through the BIA-GBS methodology, and they provide insights into the assessment of biodiversity-related transition risks.

# Un “printemps silencieux” pour le système financier? Vers une estimation des risques financiers liés à la biodiversité en France

## RÉSUMÉ

Cet article explore les risques financiers liés à la biodiversité (*biodiversity-related financial risks*, BRFR) en France. Dans un premier temps, nous proposons un cadre analytique permettant de saisir la dynamique des BRFR, insistant sur la complexité et l'incertitude en jeu ainsi que la substituabilité limitée du capital naturel. Nous proposons ensuite des premières estimations quantitatives des dépendances du système financier français à différents services écosystémiques, et de ses impacts sur la biodiversité. 42% du montant des actions et obligations détenues par des institutions financières françaises est émis par des entreprises qui sont fortement ou très fortement dépendantes d'au moins un service écosystémique. Concernant les impacts, l'empreinte biodiversité terrestre accumulée au cours du temps (empreinte dite « statique ») du portefeuille analysé est comparable à la perte d'au moins 130 000 km<sup>2</sup> de nature « vierge », ce qui correspond à l'artificialisation totale de 24% de la surface de la France métropolitaine. Enfin, sur la base du cadre analytique et des estimations proposées, l'article suggère des pistes de recherches futures.

**Mots-clés :** Biodiversité ; Stabilité financière ; Risques environnementaux ; Analyse de scénarios ; Marchés financiers et macroéconomie ; Evaluation de services écosystémiques.

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## 1 Introduction

*“Spring now comes unheralded by the return of the birds, and the early mornings, once filled with the beauty of bird song, are strangely silent. This sudden silencing of the song of the birds, this obliteration of the color and beauty and interest they lend to our world, has come about swiftly and insidiously, and has gone unnoticed by those whose communities are as yet unaffected”.*

Rachel Carson, *Silent Spring* (1962)

Biodiversity is the living fabric of our planet. However, human activities are causing a very rapid loss of biodiversity (IPBES,<sup>1</sup> 2019), and, with it, “Earth’s ability to support complex life” (Bradshaw et al., 2021). The extinction rate of species is currently 100 to 1,000 times higher than the reference rate of the past million years (IPBES, 2019), and population sizes of vertebrate species have declined by an average of 68% since 1970 (WWF, 2020). Biologists tend to consider that we are currently (or on our way to) causing the sixth mass species extinction in the Earth’s history, the last one having occurred 65 million years ago (Ceballos et al., 2015).

The risks posed by biodiversity loss to human societies, let alone to ecosystems for their intrinsic value, could be at least as high as those generated by climate change, in addition to interacting with them (Bradshaw et al., 2021; IPBES & IPCC, 2021). For instance, scientists have rung the alarm bell regarding the fact that “the risk of pandemics is increasing rapidly [...] Their emergence is caused by human activity and the impacts of these activities on the environment” (IPBES, 2020, pp. 5-6).

It is only recently that the financial community has started to pay attention to the economic and financial consequences of biodiversity loss. The Dasgupta Review on the Economics of Biodiversity (Dasgupta, 2021) stresses that the risks posed by biodiversity loss to economic and financial systems could be catastrophic, potentially triggering phenomena known as “green swans”<sup>2</sup> (Bolton et al., 2020a). The Central Banks and Financial Supervisors Network for Greening the Financial System (NGFS) has recently started investigating the linkages between biodiversity loss, macroeconomics and finance (INSPIRE & NGFS, 2021). Meanwhile, van Toor et al. (2020) have provided the first assessment at the national level (for the Netherlands) of potential financial risks related to biodiversity loss, and they find that these risks could be significant.

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<sup>1</sup> The IPBES is the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. It can be considered to be for biodiversity what the IPCC (Intergovernmental Panel on Climate Change) is for climate change.

<sup>2</sup> “Green swans” (Bolton et al., 2020a) share common features with the famous “black swans” (Taleb, 2007) insofar as they are hard to predict ex ante and can have severe consequences that are only rationalized ex post. However, green swans have three additional features (Bolton et al., 2020c; Svartzman et al., 2021): (i) scientific evidence suggests that such nature-related shocks are almost certain to occur, although the exact timing, location and impacts of these events remain highly uncertain; (ii) they involve irreversible losses (financial, material, and the loss of human lives) that may pose ethical and/or existential threats to humanity; and (iii) they cannot be hedged through individual strategies, meaning that cooperation and system change is required to mitigate such risks.

Against this backdrop, this paper provides a preliminary approximation of biodiversity-related financial risks (BRFR<sup>3</sup>) in France. More specifically, this paper makes three contributions. First, we build on previous studies to establish the rationale and the analytical framework through which central banks and financial supervisors can analyze both physical and transition biodiversity-related financial risks.<sup>4</sup> We show that the challenges related to assessing the relationships between biodiversity and the economy make it extremely difficult (if not impossible) to ‘measure’ BRFR. We emphasize issues such as the complexity and nonlinearity of ecosystem processes, the incomparability and incommensurability of the approaches through which ecosystem services can be valued, and the limited or non-substitutability of ‘natural capital’. As a result, innovative methodological approaches are needed to start exploring BRFR.

Second, we provide quantitative estimates of the dependencies of French financial institutions on ecosystem services and of the impacts of French financial institutions on biodiversity, through the securities (equities and bonds) they held at the end of 2019. These dependencies and impacts can be used to approximate or start assessing physical and transition BRFR respectively. We compute these estimates by building on two of the methodologies used by van Toor et al. (2020), to which we add some developments such as the estimate of upstream dependencies.

Overall, our results (based on data from end of 2019) indicate that the French financial system could be significantly exposed to both physical and transition risks. On the dependency side, we find that 42% of the value of securities held by French financial institutions are highly or very highly dependent on at least one ecosystem service. Regarding the impacts, we find that the accumulated (or static) terrestrial biodiversity footprint of the securities held by French financial institutions is comparable to the loss of at least 130,000km<sup>2</sup> of ‘pristine’<sup>5</sup> nature (i.e. to converting this surface of undisturbed ecosystem into a completely artificialized one). This corresponds to

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<sup>3</sup> The literature also uses the concept of nature-related financial risks (NRFR). Given that nature is a polysemic word that has not been precisely defined by biologists, we refer to BRFR. We consider that BRFR and climate-related financial risks (CRFR) are both subsets of NRFR. Moreover, it seems important to determine whether the term “ecosystem services-related financial risks” (ESFRF) would be more accurate to describe the risks explored in this study (as kindly suggested by Harold Levrel). For instance, some forms of biodiversity loss may not translate into declines in ecosystem services, and would therefore remain out of the scope of what the financial sector deems worth considering. For the sake of simplicity, we use the term BRFR in this paper, but consider that future work should seek to clarify the terms used by this rapidly growing literature.

<sup>4</sup> Following on from the need to use accurate terminology discussed in the previous footnote: (i) physical sources of risks may rather be called “biophysical” sources of risks (indeed, a biophysical environment encompasses the biotic and abiotic surrounding of an organism or population); (ii) transition sources of risks may rather be called “socioeconomic transformation” sources of risks (indeed, financial risks are more likely to emerge because of some of the far-reaching transformations of our socioeconomic system that may be required to address biodiversity loss). However, we did not have time to engage in thorough discussions about this issue, and therefore hope that future work will clarify these terms. In the meantime, we use the terms “physical” and “transition” as those are more common in the literature on NRFR, CRFR and BRFR.

<sup>5</sup> The terms “pristine”, “untouched”, “intact” and “undisturbed” nature provide a theoretical reference point, but we acknowledge that in practice socio-ecosystems are historical and evolutionary entities without an “original” state (it is doubtful that any ecosystem on the surface of the Earth has never been influenced by humans). Moreover, some “converted” areas can be more biologically diverse than “untouched” ones.

the complete artificialization of 24% of the area of metropolitan France.<sup>6</sup> Moreover, their annual additional (or dynamic) impact on terrestrial biodiversity is equivalent to the loss of 4,800km<sup>2</sup> of ‘intact’ nature, which corresponds to 48 times the area of Paris. We also assess the aquatic (freshwater) biodiversity footprint corresponding to the securities held by the French financial system but treat them separately for methodological reasons.

Third, in order to translate these findings into actual BRFR while accounting for their specific features (complexity, uncertain valuation processes, and limited substitutability), we suggest three avenues for future research. They consist in: (i) developing biodiversity-related scenarios tailored to financial risk assessment; (ii) using specific methodologies that can better capture the limited or non-substitutability of ecosystem services, as well as the nonlinear economic and financial patterns their disruption could generate; (iii) adopting a ‘double materiality’ approach (which is aligned with the recent *décret d’application* of France’s Article 29<sup>7</sup> of the 2019 Energy and Climate Act), and in particular developing new tools by means of which the alignment of financial institutions with biodiversity-related goals could be assessed.

While we provide evidence of the significant dependencies and impacts of French financial institutions on biodiversity, we also make clear that much more work will be needed to better understand how specific biodiversity-related events could affect the financial system (e.g. which shocks, which transmission channels, and which adaptive capacity of economic and financial agents). This paper is the first step, for the French financial system, into an emerging topic. The results should therefore be assessed with all relevant caveats in mind.

This paper proceeds as follows: Section 2 provides an overview of what biodiversity is, what drives its massive loss, and how its governance framework may lead to major changes that could affect economic and financial agents. This section mainly aims to provide the reader with the background needed to engage more easily with the rest of the paper. Section 3 focuses on the economic and financial dimensions of biodiversity. It provides a framework to assess the physical and transition risks related to biodiversity loss, it explains why existing economic and financial models are poorly equipped to capture the nature of these risks, and presents the ensuing approach of this paper. Section 4 describes our methodology, and the results presented in Section 5 provide material evidence of the dependencies and impacts of the French financial system on biodiversity. Section 6 discusses avenues for future research. Section 7 concludes.

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<sup>6</sup> Metropolitan France is the area of the French Republic which is geographically located in Europe. It covers a land area of 543,940 km<sup>2</sup>. We use this area as it is easier to visualize on a map. If we were to compare our results to the surface of metropolitan France and its several overseas regions and territories (total area of 640,679 km<sup>2</sup>), the static impact of the portfolio would correspond to the artificialization of 20% of the whole territory. The term ‘artificialization’ has advantages for communication purposes, but it should not be interpreted as indicating that only land use change contributes to the results.

<sup>7</sup> See: <https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000043541738>

Six decades ago, in a book that became a reference in environmental thought, Rachel Carson (1962) captured the impacts of human activity on its natural environment and on human health,<sup>8</sup> most notably the impact of pesticides on the decline in bird populations, through the expression “silent spring”. As biodiversity loss has only worsened at the global level (despite some successes at local levels) over the past decades, avoiding a “silent spring” has become critical not only from an ecological and social perspective, but also from an economic and financial one.

## 2 What is biodiversity and why should it matter to economists?

The term biodiversity, a contraction of “biological diversity” (Lovejoy, 1980), appeared in the scientific arena in the mid-1980s (Wilson, 1988). Initially promoted by biologists and conservation ecologists, it has been progressively pushed to the forefront of the political agenda since the Earth Summit in Rio de Janeiro in 1992. While biodiversity has since come into common parlance, the concept is not always well understood and it often remains confined to the diversity of species, which is a small part of what biodiversity is. Moreover, Earth and life sciences have made considerable progress in recent decades and enriched our conception of living beings and the role of biological diversity, while emphasizing the need for urgent action to reverse biodiversity loss. It is therefore important to provide a summary of what biodiversity consists of (Section 2.1), what drives its massive loss (Section 2.2) and the political processes needed to reverse its decline (Section 2.3), before delving into its economic and financial dimensions.

### 2.1 An introduction to biodiversity and ecosystem services

Biodiversity can be defined as the living part of nature (Barbault, 2006) or as the “living fabric of our planet”.<sup>9</sup> The IPBES (2019) defines biological diversity as “the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems”. These three dimensions can be briefly defined as follows (see Figure 1):

- Diversity within species: it refers to genetic and intraspecific diversity (Geist, 2011) and other forms of diversity such as behavioral, cultural and morphological diversity. Genes are not a form of life but they constitute the basis of life, and are therefore considered the ‘lowest’ level of biological diversity (except for epigenetic diversity).
- Diversity between species: this refers to the variety of species, the dimension of biodiversity that most spontaneously comes to mind. It is estimated that there are over 10 million multicellular species but only about 1.7 million are known (May, 2011), which leads some to refer to the “dark matter” of biodiversity (Chevassus-au-Louis et al.,

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<sup>8</sup> Regarding human health, Carson (1962) explores the links between the use of certain pesticides (most notably DDT) and increases in human diseases, including cancers.

<sup>9</sup> See: <https://en.unesco.org/themes/biodiversity>

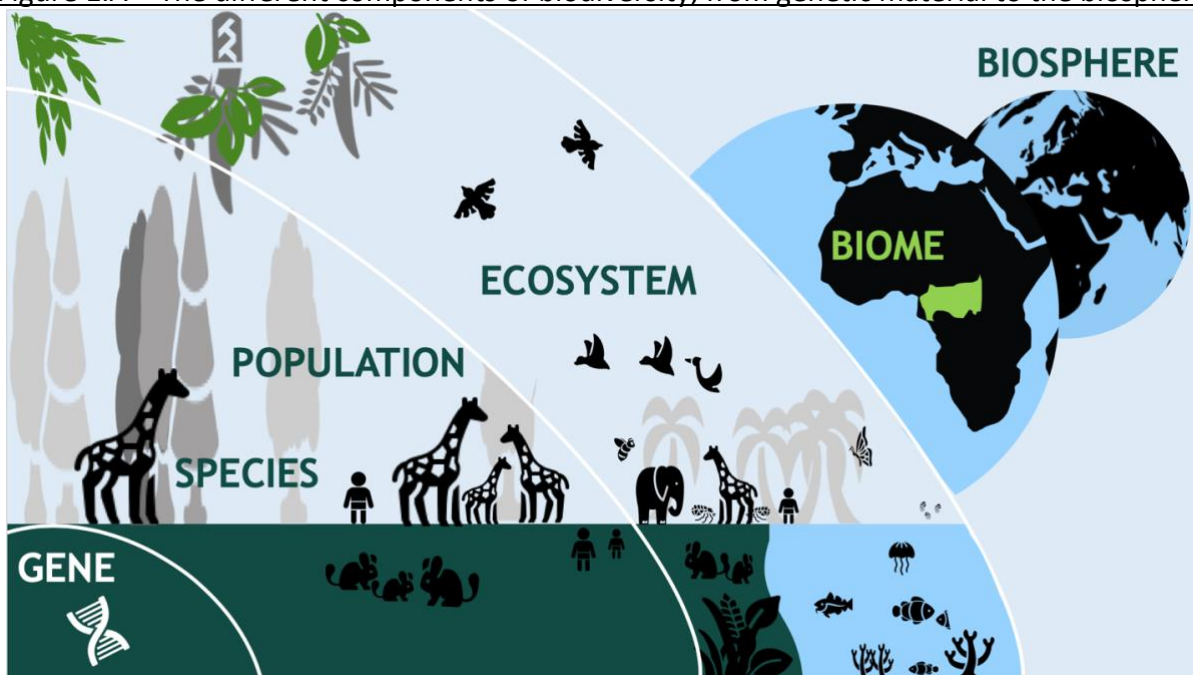


2009). Local abundance and distribution of species are key to determining the health of a species and its ability to survive. And

- Diversity of ecosystems (or ecological diversity, encompassing the functional diversity in each ecosystem and the diversity of ecosystems themselves): an ecosystem is a dynamic complex system in which communities of living beings (plants, animals, fungi, microorganisms) interact with a non-living environment defined by a set of hydrological, geological, chemical, climatic or geographical parameters. Examples of ecosystems are watersheds, wetlands, coral, mangrove forests, tropical forest and agricultural land. They provide a diversity of habitats that are necessary to the survival of species. The structures and functional interactions within these ecosystems (such as trophic chains as well as physical, chemical and information exchanges) are as important as their composition alone (Barbault, 2006). This is why some authors stress the importance of functional diversity in understanding biological diversity.

These three levels are embedded within two broader layers. The first one is biomes (or macrosystems), which encompass multiple ecosystems and form distinct biological communities. Nine terrestrial biomes are often identified (Bowman et al., 2018), including tropical rainforest, desert, tundra and temperate grassland. The second and largest layer is the biosphere, which is the global ecological system, including all living beings (named biomass by biologists) and their relationships. As the authors of the Millennium Ecosystem Assessment (MEA, 2005, p. 18) put it, “this layer of living organisms [...] physically and chemically unites the atmosphere, geosphere, and hydrosphere into an environmental system in which millions of species, including humans, have thrived”. That is, the biosphere is the total area of the Earth that is able to support life (Levin, 2009).

Figure 1.A – The different components of biodiversity, from genetic material to the biosphere



Source: authors (based on icons8), adapted from Dasgupta (2021)



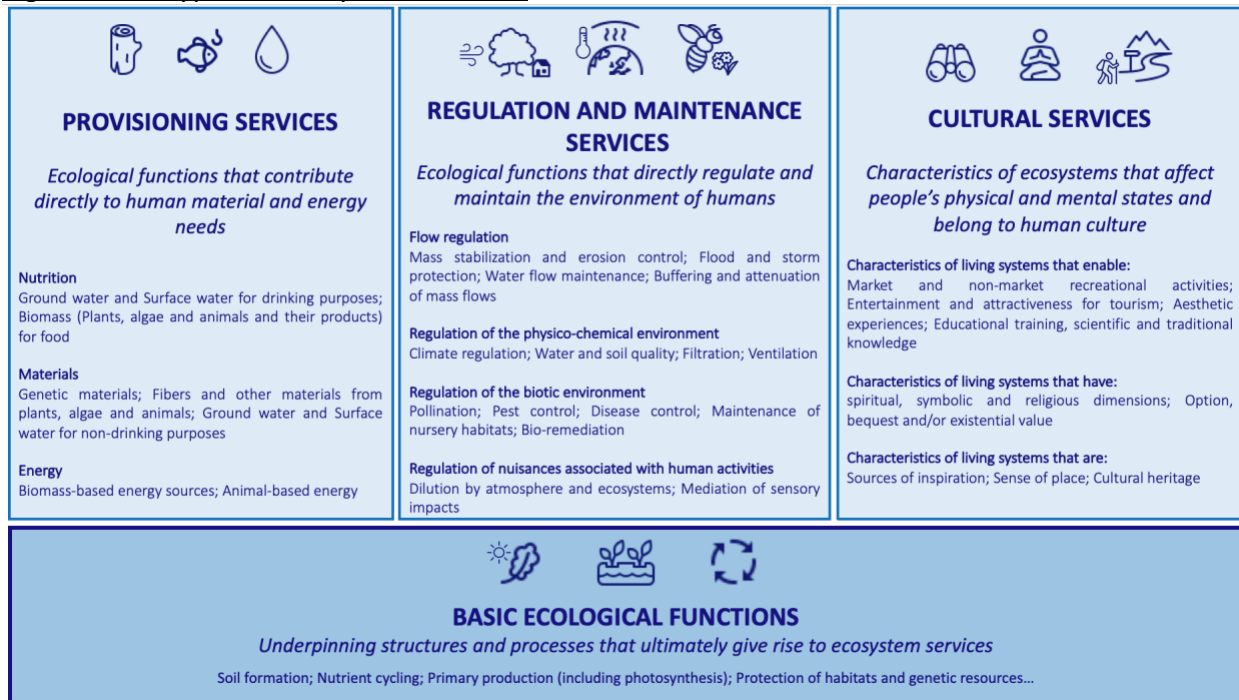
Hence, biodiversity covers not only all ecosystems and life forms (plants, animals, fungi, bacteria, and so on), but also all the relationships and interactions (such as cooperation, predation and symbiosis) that exist between the multiple organisms that populate the biosphere and between these organisms and their living environments (Gouletquer et al., 2013; MEA, 2005; Stock, 1992). Biodiversity is therefore a “multidimensional object” (Chevassus-au-Louis et al., 2009) consisting in an almost infinite network of interrelations and interactions in time and space between organisms within diverse ecosystems, which cannot be compared using a single metric. The latter has important implications when it comes to ‘measuring’ the links between biodiversity and economic and financial systems, as discussed in Section 3.

Adopting an anthropocentric framework, the concepts of “ecosystem services” (Braat et al, 2008; CGDD, 2017; Daily, 1997; Dasgupta, 2021; MEA, 2005) and, more recently, “nature’s contributions to people” (NCP) (IPBES, 2019) make it possible to capture human dependencies on ecosystems and nature more broadly, and the various benefits we derive from them. These ecosystem services are defined as the connection between an ecological function<sup>10</sup> and an actual or potential socioeconomic benefit for humans (Haines-Young & Potshin, 2018). According to the Common International Classification of Ecosystem Services (CICES, Haines-Young & Potshin, 2018), there are three different types of ecosystem services (see Figure 1.B): (i) provisioning services such as food, fuel, drinking water or pharmaceuticals; (ii) regulating and maintenance services such as pollination, climate stability, air quality or erosion control; and (iii) cultural services such as tourism or nature-related spiritual values. The maintenance of these different services is enabled by basic ecological functions (formerly called support services in the MEA (2005) framework), such as the cycle of matter, water, carbon, photosynthesis, soil formation, ecological interactions within ecosystems and the conservation of biodiversity. Ecosystem service flows can therefore be seen as the ‘dividends’ that society receives from biodiversity (TEEB, 2010). The concept of ecosystem services is now commonly used by several research communities (e.g. in ecology and environmental sciences, economics and other social sciences and humanities), policymakers, the private sector and civil society.

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<sup>10</sup> Ecological functions refer to the phenomena specific to an ecosystem and which result from the combination of its condition, ecological structures and processes. Ecological functions take place with or without the presence of human beings.

Figure 1.B – Types of ecosystem services



Source: adapted from CICES (2021)

That being said, there are many ongoing debates as to how human systems do and should value biodiversity and ecosystem services (e.g. Descola, 2005; Latour, 2016; Maris et al., 2016; Levrel, 2020). The standard approach to biodiversity in the field of economics is to consider that the value of the stock of natural resources (ecosystems, sub-soil resources), called “natural capital”,<sup>11</sup> can be captured by means of a utilitarian perspective and translated into monetary units, revealed by diverse market-based and non-market-based valuation methods. In this approach, the value of the ‘stock’ of biodiversity therefore depends on the present value of its monetized flows of ecosystem services. But this view is subject to intense debate among economists (see Maris et al., 2016; Spash & Hache, 2021). While the purpose of this paper is not to delve into such debates, it is important to note that the socially-constructed processes through which we value ecosystem services have a strong influence on how financial risks related to biodiversity loss are approached, calculated and managed. Section 3.2 therefore discusses some challenges related to the valuation of ecosystem services and its implications for the purpose and methodological approach of this study.

<sup>11</sup> Biodiversity, a characteristic of natural capital, is conceived as an enabling asset, i.e. an asset that gives value to natural capital. Indeed, biodiversity underpins the capacity of natural capital to deliver ecosystem services, as it affects the productivity, resilience and adaptability of ecosystems (Dasgupta, 2021).

## 2.2 Biodiversity loss: facts, drivers and potential consequences

### 2.2.1 Biodiversity loss: some critical facts and trends

Since the industrial revolution, and even more so in the last sixty years, the intrinsic capacity of life to diversify has been thwarted and compromised by human activities (MEA, 2005; IPBES, 2019). Human impacts on the evolution of life are responsible for the sixth mass extinction according to many scientists (Ceballos et al., 2015). Today, “around one million species of an estimated 8 million animal and plant species are already threatened with extinction [...] The global rate of species extinction is already at least tens to hundreds of times higher than the average rate over the past 10 million years and is accelerating”<sup>12</sup> (IPBES, 2019). Population sizes of vertebrate species have declined by an average of 68% over the last five decades (WWF, 2020) and the vast majority of their total biomass is composed of livestock and human beings, with only about 5% made up of wild species (Bar-On et al., 2018). Multiple other species are also affected. For instance, insects, which represent a large part of animal and plant species, are also disappearing at unprecedented rates in human history (Hallman et al., 2017; van Klink et al., 2020).

Ecosystems and habitat diversity are also greatly affected: “Natural ecosystems have declined by 47% on average, relative to their earliest estimated states” (IPBES, 2019). Old growth forests, many islands’ ecosystems and wetlands are particularly threatened. For example, the majority of wetlands, which are critical for the diversity of species, have been eradicated from the planet in the past 300 years (IPBES, 2019). Freshwater and marine environments have also been severely damaged (Bradshaw et al., 2021): in the EU, “only 38% of monitored lakes, rivers and other surface water bodies are in good chemical status” (EEA, 2018). Likewise, land areas (with 24% deemed to be in a degraded condition worldwide (IRP, 2019)) and soils (FAO, 2015) have been significantly degraded.

The impacts of human activity on biodiversity loss could rapidly become even more dramatic given the nature of ecological systems, which are subject to non-linear dynamics such as feedback loops and tipping points. Crossing critical ecological thresholds (tipping points) can lead to catastrophic and irreversible outcomes. For instance, Lovejoy & Nobre (2018) estimate that a tipping point for the Amazon system could be reached at 20-25% deforestation. Past this point, the Amazon, or at least large parts of it, could shift to a savanna vegetation, with catastrophic consequences not only for biodiversity but also for climate change, given the critical role this ecosystem plays in storing CO<sub>2</sub> emissions. A recent study (Covey et al., 2021) finds that the Amazon rainforest might already have a net warming effect.

### 2.2.2 The direct and indirect drivers of biodiversity loss

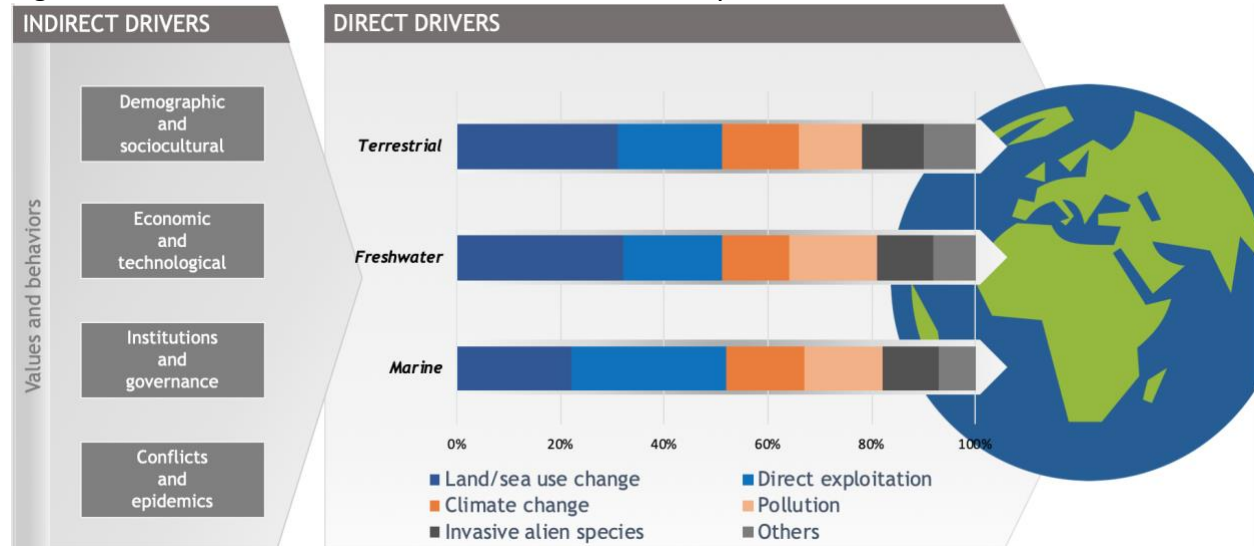
According to the IPBES (2019), five direct drivers are causing biodiversity loss. These are, from the most to the least important in terms of worldwide impacts: land- and sea-use change; direct natural resources exploitation; climate change; pollution; and invasive alien species (see Figure

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<sup>12</sup> Some classes of species are more threatened: 40% of amphibians, 33% of coral reefs, 26% of mammals and 35% of conifers are threatened with extinction.

2). This order of importance can nevertheless vary depending on specific ecosystems (e.g. oceans are mainly altered by direct exploitation of fish and seafood) and locations (e.g. islands tend to be more vulnerable to invasive alien species than continental areas).

Figure 2 – The direct and indirect drivers of biodiversity loss



Source: authors (based on icons8), adapted from IPBES (2019)

The two most important drivers (land- and sea-use change, and direct exploitation) are closely related, and their relative importance diverge between terrestrial and freshwater ecosystems, and marine ecosystems. For terrestrial and freshwater ecosystems, land-use change (artificialization) is causing the largest negative impact on nature, followed by the overexploitation of living organisms, mainly via harvesting, logging, hunting and fishing. For example, over half the Earth’s land surface has now been converted for anthropic uses, including agricultural lands,<sup>13</sup> pasture and range lands, and cities (IPBES, 2019). For marine ecosystems, the overexploitation of organisms (mainly fishing) is the main pressure, followed by sea-use changes, mainly via coastal developments for infrastructure and aquaculture. For instance, nearly 75% of the major marine fish stocks are currently depleted or overexploited (IPBES, 2019).

The third most important driver of biodiversity loss is climate change. For example, climate change is increasingly driving deforestation through droughts, warmer temperatures and stronger storms (WRI, 2021), potentially leading to rainforests turning into savannas (Araújo et al., 2021). Coral reefs could decline by 70-90% with global warming of 1.5°C and disappear with global warming above 2°C (IPCC, 2018). Moreover, positive feedback loops can take place between biodiversity loss and climate change. For instance, deforestation caused by climate change might not only cause irreversible damage to local ecosystems but also dangerously exacerbate climate change by releasing even more CO<sub>2</sub>, which could in turn cause even more

<sup>13</sup> The most widespread form of land cover change is driven by agricultural expansion, with over one third of the terrestrial land surface currently being used for cropping or animal husbandry at the expense of forests, wetlands, prairies and many other natural land cover types.

deforestation (e.g. through increased droughts and fires). Climate change and biodiversity loss can also combine to strengthen specific patterns, such as increasing the risks of pathogens crossing the barrier between humans and animals (Calas et al., 2020; IPBES & IPCC, 2021; Lugassy et al., 2021). However, solving one issue does not automatically lead to solving the other, as is often believed. In particular, some scenarios aimed at decarbonizing the global economy are being criticized for their potentially disastrous impacts on biodiversity, most notably because of the land-use change that would be required for negative emissions (Capellán-Pérez et al., 2017; Deprez et al., 2021; IPBES & IPCC, 2021).

Fourth, multiple forms of air, water and soil pollution also contribute to biodiversity loss. For instance, marine plastic pollution is up tenfold since 1980; up to 400 million tons of industrial toxic waste and heavy metals are discharged into waterways annually; and more than 100 million tons of mineral nitrogen fertilizers are applied each year to crops, with massive consequences on natural habitats (World Bank, 2020). Concerns are also growing about micropollutants stemming from farming, industrial and domestic products (e.g. pharmaceutical waste, fuels, textiles, phytosanitary and veterinary products, cosmetics and detergents), which can impact living beings even at very low levels (e.g. endocrine disruptors).

Fifth, invasions of alien species are destroying natural habitats and reducing the diversity of living organisms' populations. For instance, the cumulative records of alien species have increased by 40% since 1980 (World Bank, 2020). While the marine environment (mostly through aquaculture and shipping (Dasgupta, 2021)) and endemic and specialized species on islands are particularly vulnerable to invasive alien species, continental biodiversity is also under threat (see for example European Commission Staff working document, 2013).

These five direct drivers result from a set of underlying causes, the so-called indirect drivers of change (see Figure 2 above). These indirect drivers relate to social values and behaviors (which differ in intensity among regions, countries and groups of individuals), and they include production and consumption patterns, demographic dynamics and trends, trade, technological innovations and governance from the local to the global level (IPBES, 2019). Addressing the indirect drivers of biodiversity loss may call for profound or “transformative changes” (IPBES, 2019) in our global socioeconomic system, as will be further discussed below with regard to financial stability.

### 2.2.3 Socioeconomic consequences of biodiversity loss

We discuss the economic and financial consequences of biodiversity loss in greater depth in Section 3, but provide in this section an initial overview of its potential socioeconomic impacts. The human-led pressures on biodiversity have already started to affect the ability of nature and ecosystems to deliver regulation and maintenance services, such as carbon sequestration, flood protection, water pollutant filtration, disease control, pollination, and regulation of extreme events. For example, because of biodiversity loss, agricultural yields are already decreasing, according to the IPBES (2019). Poorer water and air quality, as well as more frequent and intense flooding and fires are also already compromising human health in multiple locations (Bradshaw et al., 2021).

We should nevertheless bear in mind that these impacts are likely to increase and that many indirect impacts could be at play, with more difficult quantitative estimates. For instance, many experts have argued for quite some time<sup>14</sup> that new pandemics could emerge because of biodiversity loss, and that the vast majority of new pathogens in recent decades are zoonoses (Morens et al., 2020; Bradshaw et al., 2021). Organizations such as the IPBES (2020, p. 2) now argue that failing to reverse biodiversity loss would mean that pandemics could “emerge more often, spread more rapidly, kill more people, and affect the global economy with more devastating impact than ever before”.

In short, although climate change has captured most of the attention with regard to human-environmental interactions, scientific evidence shows that “the impacts of biodiversity loss on ecological processes may well be sufficiently large to rival the impacts of the other major global drivers of environmental change, such as fires, nitrogen overload and rising carbon concentration in the atmosphere” (Dasgupta, 2021, p. 75).

The economic costs of biodiversity loss can therefore be significant. Using a standard economic assessment framework and updating a previous famous study (Costanza et al., 1997), Costanza et al. (2014) estimate that the annual value of ecosystem services (including drinking water, food and pollination, among others) amount to USD 125 trillion, i.e. about 1.5 times global GDP.<sup>15</sup> This value, a conservative one according to the authors, represents what we would lose each year if the ecosystem services considered by the study were to disappear or become non-functional. Other economic estimates of the costs of biodiversity loss focus on more narrow geographical areas or sectors. For example, Gallai et al. (2008) estimate the value of pollination services at around EUR 150 billion per year (2005 value) at the global level, which represents 9.5% of the total value of crop production.

However, as will be discussed in Section 3, one of the key challenges related to assessing the economic importance of biodiversity is that existing models and analytical frameworks used in standard environmental economics do not easily do justice to the scientific community’s findings that biodiversity loss can lead to potentially catastrophic consequences for human societies, let alone for non-human populations. Put differently, existing efforts aimed at monetizing ecosystem services are often subject to many methodological and epistemological challenges (see Maris et al., 2016; Spash & Hache, 2021) that mean that their results should be assessed with great caution.

Of particular importance for the purpose of this study, existing financial risk assessment methods that build on existing biodiversity-economic models could easily underestimate the tail risks related to biodiversity loss. There are various reasons (further discussed in Section 3.2) for this,

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<sup>14</sup> The IPBES (2019) wrote that “zoonotic diseases are significant threats to human health [...] Emerging infectious diseases in wildlife, domestic animals, plants or people can be exacerbated by human activities such as land clearing and habitat fragmentation [...] or the overuse of antibiotics driving rapid evolution of antibiotic resistance in many bacterial pathogens”.

<sup>15</sup> Swiss Re Institute (2020) finds that 55% of global GDP depends on highly-functioning ecosystem services.

in particular: the complexity of ecosystems, including non-linearity patterns; the social values embedded in monetary valuation processes, which by definition reduce multiple values and indicators to a single metric; the difficulty in accounting for the institutional transformations (or structural change) needed to address biodiversity loss; and the limited substitutability of ‘natural capital’. These challenges explain the ad hoc approach followed in this paper and discussed in Section 3.3.

### 2.3 Biological diversity loss in the international governance agenda – Towards a “mainstreaming” of biodiversity

Against this backdrop, biodiversity loss is increasingly acknowledged in the international governance agenda, with many implications for regional and national agendas (See Annex 1.A for a focus on the EU and France). Moreover, the governance of biodiversity is moving from an isolated topic (focused on preserving biodiversity through national parks, for instance) to an integrated approach with implications for multiple economic sectors.

The foundation stone of international governance in terms of biodiversity was the Earth Summit in Rio in 1992, which led to the adoption of the United Nations Convention on Biological Diversity (CDB) and a series of non-binding targets to be set at the national level by all signatory countries. The Nagoya Conference, in 2010, strengthened these objectives, leading to what became the Aichi targets, made up of 20 objectives structured around five strategic goals. However, the majority of the Aichi targets have not been met.<sup>16</sup>

The next Convention on Biological Diversity Conference of the Parties (COP 15) will take place in Kunming, China. It will report on the progress made since the adoption of the 2010 Aichi Targets and will seek to set a new direction for the next decade. In this context, expectations are that the COP 15 will become a major international agreement, much like the Paris UNFCCC’s COP 21 has been with regard to climate change. The goal is to adopt a Global Biodiversity Framework (GBF) for the 2021-2030 period, which should cover five main goals<sup>17</sup> divided into three main areas: (i) reducing threats to biodiversity, including by protecting 30% of terrestrial, freshwater and marine areas by 2030; (ii) meeting the needs of populations through the sustainable use and sharing of the benefits of biodiversity; and (iii) the implementation of operational tools and solutions and the crosscutting integration of biodiversity (or “biodiversity mainstreaming”).

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<sup>16</sup> For instance, only 7.7% of marine areas are now protected instead of 10%. The goal of protecting land and inland water areas is much closer to being met at first sight (16.6% officially protected versus a goal of 17%), but the management of these protected areas is often not (or only partially) effective and not always equitable (UNEP, 2021).

<sup>17</sup> These five goals are: (i) the absence of net loss of surface area and integrity of freshwater, marine and terrestrial ecosystems; (ii) a reduction in the percentage of threatened species at the same time as an increase in the abundance of species (values of variations are under negotiation); (iii) the preservation or increase (to be quantified) of genetic diversity; (iv) an improvement in the benefits provided by nature to a portion (to be quantified) of the population in terms of nutrition, access to drinking water and resilience to natural disasters; and (v) an increase in the fairly and equitably shared benefit from the use of genetic resources and associated traditional knowledge (to be quantified).



The third area includes the role of financial flows in achieving the objectives of the post-2020 GBF. While the financing needs to preserve global biodiversity are estimated at between USD 722 billion and USD 967 billion per year until 2030 (about 1% of global GDP), only USD 125 to USD 143 billion are spent each year, i.e. about six times less (Deutz et al., 2020; Tobin-de la Puente & Mitchell, 2021). About 25% of this financing should be directed toward biodiversity conservation (for terrestrial and marine protected areas and key biodiversity hotspots), meaning that the bulk of the financing should be used to better mainstream biodiversity in the economic sectors that harm it, including fishing, forestry, agriculture and construction. Moreover, while investments ‘in’ biodiversity are needed in some cases, addressing biodiversity loss also requires many regulatory changes that will affect economic agents but cannot be captured through the concept of investment. For example, protecting natural resources may imply a net reduction in investment in some cases, and changes in business practices or consumption habits that do not translate into specific investments.

These developments suggest that in order to address the risks related to biodiversity loss, many institutional changes need to take place, which could have significant impacts on multiple economic sectors and agents (see Annex 1.B). The IPBES refers to the concept of “transformative changes”, understood as being “a fundamental, system-wide reorganization across technological, economic and social factors, including paradigms, goals and values” (IPBES, 2019). Through the lens of transformative changes, new priorities beyond the need to measure and internalize environmental externalities emerge, including the need to “embrace diverse visions of a good life [...] reduce total consumption [...] and inequalities” (IPBES, 2020, p. 40). Some implications of such transformative changes for the purpose of this study are further discussed in Section 3.2.

### 3 Biodiversity-related financial risks (BRFR) – Rationale, challenges and approach of the paper

#### 3.1 From the recent and rapidly growing awareness of BRFR to an analytical framework

Over the past few years, it has been increasingly acknowledged that economic and financial stability can be threatened by environmental degradation. While the vast majority of the work in this field has focused on climate-related financial risks (CRFR), the topic of biodiversity-related financial risks (BRFR) is now gaining momentum very rapidly in many political and economic spheres (e.g. World Economic Forum, 2021). Policymakers (e.g. G7, 2021; OECD, 2019), civil society organizations (e.g. Finance Watch, 2019; WWF, 2020), private-sector initiatives (e.g. Chandellier & Malacain, 2021; TNFD, 2021), academic scholars (e.g. Dasgupta, 2021; Kedward et al., 2020, 2021) have all discussed how biodiversity loss, and/or the fact that economic agents are dependent on activities that erode biodiversity, could generate financial instability. They have proposed several frameworks and arguments, which are summarized in Annex 1.C.

In light of the above, the central banking and financial supervision community is increasingly looking at BRFR. The NGFS Charter<sup>18</sup> and its first Comprehensive Report (NGFS, 2019) already acknowledged the existence of environmental risks beyond climate change. Building on this, INSPIRE & NGFS (2021) have started to explore why and how central banks and financial supervisors could further work on this issue.

The central bank of the Netherlands (van Toor et al., 2020) has provided the first comprehensive national assessment of how financial institutions are exposed to different risks related to biodiversity loss. The authors find that 36% of financial institution portfolios of listed shares in the Netherlands are highly or very highly dependent upon at least one ecosystem service, and that the biodiversity footprint of Dutch financial institutions is comparable to the loss of 58,000 km<sup>2</sup> of pristine nature, equivalent to more than 1.7 times the land surface of the Netherlands. Calice et al. (2021) replicate some of the methodologies used by the DNB for Brazil. They find, among other things, that 45% of the total corporate loan portfolio of Brazilian banks is exposed to sectors that are highly or very highly dependent on one or more ecosystem services, and 15% is exposed to firms that operate in areas that are already protected or could become protected in the near future.

Importantly, forthcoming financial regulations could systematize the assessment of BRFR. In France in particular, Article 29 of the 2019 Energy Climate Act<sup>19</sup> states that financial players will have to incorporate BRFR into their reporting practices (through the concept of double materiality, as discussed further in Section 6.3). The supervisory authorities of French banks and insurers (ACPR et al., 2020, pp. 76-77) have also acknowledged that much like climate change, the increasing awareness of the risks posed by biodiversity loss could lead to increased regulatory expectations around this issue.

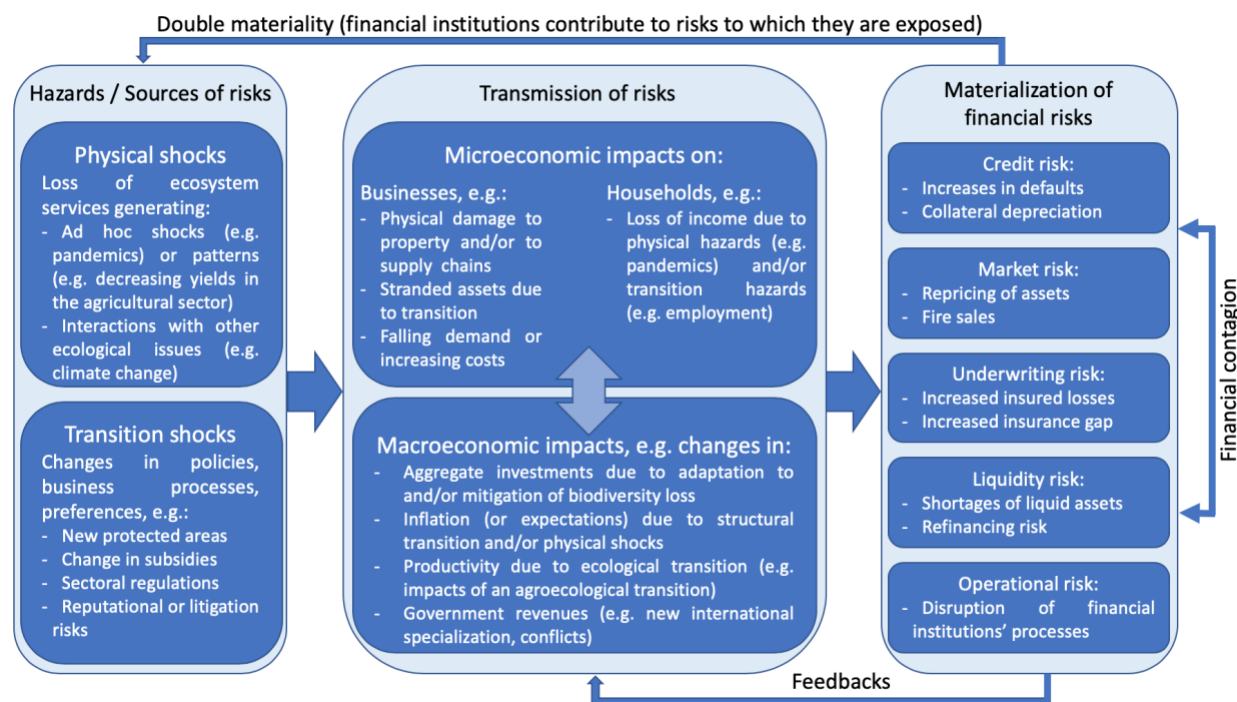
In this context, our first contribution in this paper is to build on the incipient initiatives, described above and in Annex 1.C, to refine the analytical framework through which we can understand BRFR. Building on previous graphic representations of CRFR (in particular, Bolton et al., 2020b; NGFS, 2020) and BRFR (in particular, INSPIRE & NGFS, 2021; van Toor et al., 2020), we suggest assessing BRFR by means of the framework set out in Figure 3.

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<sup>18</sup> See: [https://www.ngfs.net/sites/default/files/media/2020/09/03/ngfs\\_charter\\_final.pdf](https://www.ngfs.net/sites/default/files/media/2020/09/03/ngfs_charter_final.pdf)

<sup>19</sup> See: <https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000039355955/>

Figure 3 – An analytical framework to explore biodiversity-related financial risks (BRFR)



The left-hand side of Figure 3 indicates that much like for CRFR, biodiversity-related events can impact financial stability through so-called physical risks and transition risks<sup>20</sup>. These are in fact not *risks per se* but *sources of risks, shocks or hazards* that can ultimately translate into financial risks under certain circumstances (for real-world case studies of biodiversity-related financial risks, see WWF, 2021c, forthcoming). Physical biodiversity-related sources of risks are linked to the five direct drivers of biodiversity loss described above. The latter can translate into hazards of a chronic nature (e.g., the use of pesticides leading to a gradual decline of pollinators, a decrease in soil fertility and a fall in agricultural yields), or acute nature (e.g. deforestation resulting in a zoonotic disease and ensuing pandemic). Physical shocks may be located at a local (e.g. loss of agricultural output<sup>21</sup> in one region) or at a global level (e.g. disruption of supply chains or an unprecedented fall in aggregate demand due to a pandemic). At scale, physical-related sources of risks could also influence geopolitical patterns (e.g. through migration and conflicts), leading to unanticipated threats to financial stability.

Transition-related sources of risks could also emerge if financial institutions' activities (like loans, investments or insurance policies) become misaligned or incompatible with new policies and regulations (like ending a harmful subsidy or protecting a new area) or other developments such as rapid changes in consumer preferences or technologies related to the need to protect biodiversity. Transition shocks can also be very local (for example, changes in agricultural subsidies affecting farmers in one region) or more global (like modifications of trade agreements

<sup>20</sup> We consider that litigation and reputational risks are part of physical or transition.

<sup>21</sup> For more details on nature risks and agriculture, see for example WWF (2021b).

to deal with imported deforestation issues, which could entail losses of revenue for some countries). In practice, transition-related sources of risks may not materialize in the form of ‘shocks’ but rather through more or less rapid socioeconomic transformations, which could challenge existing economic and financial structures and interests.

In short, BRFR can emerge from two main categories of hazards (physical and transition sources of risks) but impact economic activities through multiple channels (e.g. at the household, corporate, sectoral or macroeconomic levels) before materializing as typical financial risks such as credit risk or market risk. Moreover, physical and transition sources of risk could merge, and multiple contagion channels could appear between different financial risks (financial contagion arrow in Figure 3), with potential feedback loops on the economic system. Lastly, it is important to recall that BRFR are partly endogenous (Chenet et al., 2021), insofar as financial institutions also contribute to biodiversity loss through their loans and investments (as shown in Figure 3 through the arrow of ‘double materiality’, a concept that is discussed further in Section 6.3).

### 3.2 The challenge of evaluating biodiversity-economic-financial relationships

Figure 3 above suggests that before being able to assess BRFR, one needs to evaluate how physical and transition sources of risk can affect macroeconomic and microeconomic structures, and their complex interactions. In other words, before evaluating the links between biodiversity and financial stability, the first step consists in assessing the biodiversity-economy nexus. For instance, Johnson et al.’s (2021) “global Earth-economy model” aims to estimate how the collapse of specific ecosystem services – such as wild pollinators, marine fisheries and timber provision from tropical forests – could affect the global economy. The authors find that effects on the global economy could be significant, particularly in low-income economies that could see a 10% drop in GDP by 2030. Building on the results of the model for Brazil, Calice et al. (2021) provide a pioneering estimate of biodiversity-related physical risks: based on the historical sensitivity of Brazilian banks’ asset quality to macroeconomic conditions, they find that the output losses associated with the model (Johnson et al., 2021) could translate into a cumulative long-term increase in corporate nonperforming loans of 9 percentage points.

Despite such major breakthroughs, the methods by which the biodiversity-economy relationships can be assessed and translated into monetary terms remain inherently subject to many uncertainties (see INSPIRE & NGFS (2021)) and debates, and this can affect the robustness of ensuing financial risk assessments (as acknowledged by Calice et al. (2021) for instance). We identify three main (and interconnected) limitations at play:<sup>22</sup> (i) the complexity of ecosystem processes, including the possibility of crossing tipping points; (ii) the incomparable and incommensurable processes through which ecosystems can be valued; and (iii) the low- or non-substitutability of natural capital.

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<sup>22</sup> It is noteworthy that these limitations apply in large part to CRFR (see Bolton et al., 2020a) but become even more evident (and therefore more important to take account of) when it comes to BRFR.

### 3.2.1 The complexity of ecosystem processes, including non-linear patterns related to the possibility of crossing tipping points

First, understanding the economic consequences of potential biodiversity-related shocks requires understanding the functioning of ecosystems. A major difficulty in this respect relies on the non-linearity and complexity of ecosystems. As complex adaptive systems, they are characterized by multiple interactions among natural processes and living organisms (including humans), which means that it is not possible to ever know all the possible outcomes of an event (Kedward et al., 2020). One dimension of this complexity is that, unlike for climate change where universal metrics (tons of CO<sub>2</sub> equivalent) are relevant, “it is illusory to hope to describe biodiversity by a single indicator” (Chevassus-au-Louis et al., 2009). Biodiversity measurement requires multiple indicators to capture progress across various spatial and ecological dimensions (species richness, species population, ecosystem integrity, etc.). This means that BRFR are composed of interconnected threats (e.g. soil erosion, invasive species, groundwater depletion, species loss) which are the result of diverse anthropogenic drivers (e.g. intensive agriculture, chemical pollution, deforestation) acting at different levels from local ecosystems to planetary processes (Kedward et al., 2020).

Moreover, many components of the living world remain simply invisible to humans: “Nearly all organisms that help to produce those services are hidden from view (a gram of soil may contain as many as 10 billion bacterial cells)” (Dasgupta, 2021, p. 53). In short, the potential sources of BRFR are even more complex to capture than in the case of CRFR (PwC & WWF, 2020).

Even more critically from the perspective of assessing financial risks, ecological systems are subject to non-linear dynamics such as feedback loops and tipping points (although linear impacts of biodiversity loss can also lead to catastrophic outcomes). While there is a consensus on the fact that crossing critical ecological thresholds (‘tipping points’) can lead to catastrophic and irreversible outcomes (Rockström et al., 2009; Steffen et al., 2015), it remains challenging to predict with precision where these thresholds are (Hillebrand et al., 2020; Lovejoy & Nobre, 2018). As a result, assuming that the loss or protection of ecosystem services can be precisely measured could miss the tail risks related to BRFR, like the occurrence of pandemics related to biodiversity loss (IPBES, 2020). Recent studies on BRFR (e.g. Dasgupta, 2021; Chandellier & Malacain, 2021) emphasize that the concept of green swans is particularly relevant when dealing with biodiversity. In this context, it is impossible to build on existing risk models to anticipate BRFR.<sup>23</sup>

Note that the existence of tipping points can also have an indirect impact on the measurement of transition risks. Dasgupta (2021, p. 189) explains that, because of the non-linearity in the processes governing the biosphere, quantity restrictions are preferable to Pigouvian taxes and subsidies (which would need to vary by ecosystem and level of degradation over time, with

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<sup>23</sup> A parallel can be drawn with the concept of systemic risk in finance, i.e. the risk of collapse of the entire financial system. Following the 2007-08 Global Financial Crisis, the Basel Committee on Banking Supervision (BIS, 2011) acknowledged the limitations of existing risk models and called for alternative approaches and metrics (e.g. relatively simple aggregate financial indicators such as credit-to-GDP ratios, and non-financial indicators such as cross-jurisdictional activity and interconnectedness) that are deemed better suited to hedging against systemic risks.

perfect knowledge of the marginal social utility of biodiversity protection) to address biodiversity loss. However, most economic models, in which agents respond more or less exclusively to price signals, are poorly equipped to deal with 'quantity' (rather than price) signals (see Svartzman et al., 2021).

### 3.2.2 The incommensurability and incomparability of ecosystem services' valuation processes

Second, in order to assess BRFR, we would like to understand how economic activity reacts to potential change in the provision of ecosystem services. However, understanding the contribution of ecosystem services and their importance for economic activity is far from easy. A key aspect of this difficulty can be found in the literature on the economic valuation of natural capital and ecosystem services provided by biodiversity. Indeed, many different values can be assigned to a given ecosystem service, depending on the definition of value that is adopted, the purpose of the valuation, the methodology used, and the person or group by whom the valuation is made.<sup>24</sup>

Therefore, the relationships between variations in biodiversity and variations in ecosystem services, which are used to assess the economic value of biodiversity in environmental economics, are not clear. In practice, policy mechanisms based on the monetization of ecosystem services are often found to lead to trade-offs between different ecosystem services (Muradian & Rival, 2012), for example, by valuing forests for their ability to sequester carbon at the expense of other essential functions such as nutrient cycling or biodiversity preservation.<sup>25</sup>

The standard economic process of monetizing ecosystem services (in fact their variation, i.e. the loss in gain of these services) using methods aimed at assessing values comprised in the "total economic value" framework (Pearce & Moran, 1994) often corresponds to a utilitarian valuation of nature: something has value if and only if it has a subjective utility for an economic agent such as an individual or a firm.

In contrast, a growing literature (e.g. IPBES, 2019; Maitre d'Hôtel & Pelegrin, 2012; Roche et al., 2016) tells us that nature can be described and valued through many different dimensions depending on whether one refers to environmental science (i.e. biodiversity, species, genes), social sciences and humanities, interdisciplinary environmental science (e.g. nonhuman and natural heritage values), knowledge systems (e.g. where concepts such as Pachamama denote different human-nonhuman relationships) or standard economic theory (e.g. natural capital). These diverse values and corresponding worldviews are increasingly acknowledged by

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<sup>24</sup> In fact, some of the challenges discussed here also apply to the measurement of manufactured capital, as shown by the "Cambridge capital controversy": some post-Keynesian economists have argued that neoclassical economic theory suffers from circular logic when aggregating the net present values of heterogeneous forms of capital within a single category of manufactured capital (see e.g. Cohen & Harcourt, 2003; Spash & Hache, 2021). Suffice to say for the purposes of this paper that such considerations become particularly relevant when assessing natural capital.

<sup>25</sup> Moreover, numerous scientific studies establish a direct relation between biodiversity, carbon storage and resilience (especially in the face of droughts) in the forestry and agricultural sectors (e.g. Tilman et al., 1996).



environmental public policies (e.g. European Commission, 2011; French Ministry of Ecology, 2019<sup>26</sup>).

Thus, biodiversity is composed of multiple ecosystems and relationships with incomparable and incommensurable values (Kolinjivadji et al., 2017; Kosoy et al., 2012; Svartzman et al., 2019). In this context, aiming to find the ‘true’ or ‘fundamental’ value of an ecosystem can lead to imposing certain ways of valuing (certain aspects of) nature that can serve certain groups of people while being detrimental to others, including the world’s poorest. In some cases, incentive schemes and mechanisms such as payments for ecosystem (or environmental) services (PES) have been found to crowd out the ‘pro-protection’ attitude that existed among landowners, or at least fail to make such an attitude emerge (Vatn, 2010), and market-based tools are often found to be ineffective in channeling private finance to conservation activities (Suttor-Sorel & Hercelin, 2020)<sup>27</sup>.

This does not suggest that biodiversity loss should not be discussed using monetary values, but rather that such values should be considered as the result of ‘conventional’ exercises aimed at raising awareness (Laurans, 2013), in which the valuation process itself is at least as important as the result (Hérivaux & Gauthey, 2018). For instance, the “inaction cost”, i.e. the economic value we are losing due to the lack of political action and individual and collective behavior changes to protect nature, mitigate its degradation or restore it (Braat & ten Brink, 2008; Chevassus-au-Louis et al., 2009; Heal, 2005) can provide relevant monetary metrics for policymakers at the microeconomic or macroeconomic level (Levrel et al., 2021, 2014). In this vein, a recent study (Diagne et al., 2021) finds that invasive species (one of the five direct drivers of biodiversity loss) have cost more than USD 25 billion per year on average from 1970 to 2017, with a sharp increase in recent years. These costs include agricultural losses, falls in tourism revenues and health costs due to hospitalization, among many others.

### 3.2.3 The low substitutability of natural capital and the case for a stronger sustainability approach

A third challenge related to the assessment of the biodiversity-economy nexus has to do with the level of substitutability of biodiversity and ecosystem services. Most biodiversity-economy (and climate-economy) models do not account for the non-substitutability of natural capital, and fall within what is often called a “weak sustainability” approach (Daly & Farley, 2011; Dietz & Neumayer, 2007): what matters is that capital as a whole (measured in monetary terms) increases, and the loss of natural capital becomes important only insofar as it threatens the accumulation of physical and human capital.

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<sup>26</sup> For example, the conceptual framework developed by the French assessment of ecosystems and ecosystem services (EFESE. French Ministry for the Ecological Transition , 2019), the French equivalent of the MEA, recognizes three categories of non-commensurable values to account for the values of biodiversity and associated ecosystem services: (i) utility value, i.e. the ability of the ecosystem to sustainably provide ecosystem goods and services; (ii) heritage value, i.e. the state of conservation of elements of the ecosystem recognized as remarkable; and (iii) ecological value, i.e. the ecosystem’s resistance and resilience in the face of disturbances.

<sup>27</sup> For instance, valuing protected areas through market-based approaches could easily lead to displace Indigenous Peoples living in these areas, given that they do not contribute significantly to total output and that their monetary ‘willingness to pay’ for staying in their local environment tends to be limited by their income.



Monetary estimates of ecosystem services can easily lead to problematic conclusions when assessed within a “weak sustainability” paradigm (putting aside the other limitations discussed above). For instance, since pollination is found to contribute to £510-690 million per year to the United Kingdom's agricultural production (Breeze et al., 2012, cited in Dasgupta, 2021), corresponding to 0.03% of the UK's GDP in 2019, then the “weak sustainability” approach suggests that losing all pollinators would only result in a very small economic loss. In this case, as asked by Dasgupta (2021, p. 324), “Why care whether any pollinators are left?”. Likewise, macroeconomic assessments suggesting that not acting on biodiversity loss could cost a few points of GDP by 2050 could be interpreted by financial supervisors as an indication that biodiversity loss hardly represents any risk at all.<sup>28</sup>

In contrast, the “strong sustainability approach” (Daly and Farley, 2011; Dietz & Neumayer, 2007) considers that existing stocks of natural capital cannot (or only very partially) be offset by an increase in manufactured or human capital. That is, the depletion of natural capital and ecosystem services in a world of collapsing biodiversity (or climate change) cannot be offset by higher income (or only to a very limited extent): “If the biosphere was to be destroyed, life would cease to exist” (Dasgupta, 2021, p. 47). Using the example of pollination above, this means that “pollinators may be of great value even if their measurable services to GDP are of negligible worth” (Dasgupta, 2021, p. 324). Moreover, the question of substitutability within a specific dimension of natural capital (e.g. are two specimens of the same species substitutable, and in what respects?) remains unanswered.

Many initiatives have been developed in recent years to account for the unique role played by natural capital. The concept of inclusive wealth (UNEP, 2018), which adds up the produced, human and natural forms of capital, partially accounts for limited substitutability insofar as it allows for assigning non-market values to natural capital that are so high that in practice they enable “little-to-no substitution possibilities between key forms of natural capital and produced capital, or for that matter any other form of capital” (Dasgupta, 2021, p. 330). Other accounting frameworks account even more explicitly for the non-substitutability of natural capital. For instance, models developed at the corporate level (see Féger & Mermet, 2020; WWF, 2019), such as the CARE-TDL model (Rambaud & Richard, 2015), consider that natural capital should be maintained for its own sake. As a result, the monetary valuation is made by calculating the maintenance cost of natural capital, i.e. the costs that a firm would incur to maintain or restore the ecosystem services it depends on. However, these accounting frameworks remain in their infancy and have not yet been addressed from the perspective of financial stability (Rambaud & Chenet, 2020). That is, the question of what limited substitutability means for the financial system is still under-addressed.

These three related limitations (complexity of ecosystems, incomparable and incommensurable valuation processes, and limited substitutability of natural capital) suggest that addressing BRFR will require much more than finding the ‘right’ biodiversity-economy model or bridging specific

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<sup>28</sup> A similar conclusion might be reached if one looks at many assessments of the economic cost of climate change (see Keen, 2020).

data gaps. According to some (e.g. Kedward et al., 2020), BRFR are actually best understood through the concept of deep or radical uncertainty.<sup>29</sup>

Moreover, a growing body of literature suggests that addressing biodiversity loss will require undertaking far-reaching or “transformative changes” (IPBES, 2019). Indeed, to mention just a few examples discussed in the literature (see Annex 1.B for more details), addressing biodiversity loss may require relying increasingly on alternative metrics to GDP (e.g. Dasgupta, 2021), developing ad hoc property regimes to manage common pool resources (Ostrom, 2009), revisiting trade specialization or rethinking the role of finance and investment for a finite planet (see Annex 1.B).

While delving into these issues goes far beyond the scope of this paper, ignoring them could easily lead to missing the main sources of ecological and socioeconomic transformations that could ultimately translate into financial risks.

### 3.3 Approach of the paper – Approximating physical and transition risks using ad hoc methodologies

In this context, the logical way forward is to conduct scenario analysis<sup>30</sup>, just like in the case of CRFR (NGFS, 2019, 2020). Unlike probabilistic approaches to financial risk management, scenario analysis seeks to put forward plausible hypotheses for the future, by developing forward-looking risk assessments that do not need to (indeed cannot) be informed by backward-looking economic and financial data. For financial supervision purposes, scenario analysis can be used to assess the vulnerability of specific institutions and the financial system as a whole to specific shocks (see for instance the stress tests conducted by regulatory authorities to assess the resilience of banking institutions in an adverse macro-financial scenario (Borio et al., 2014)).

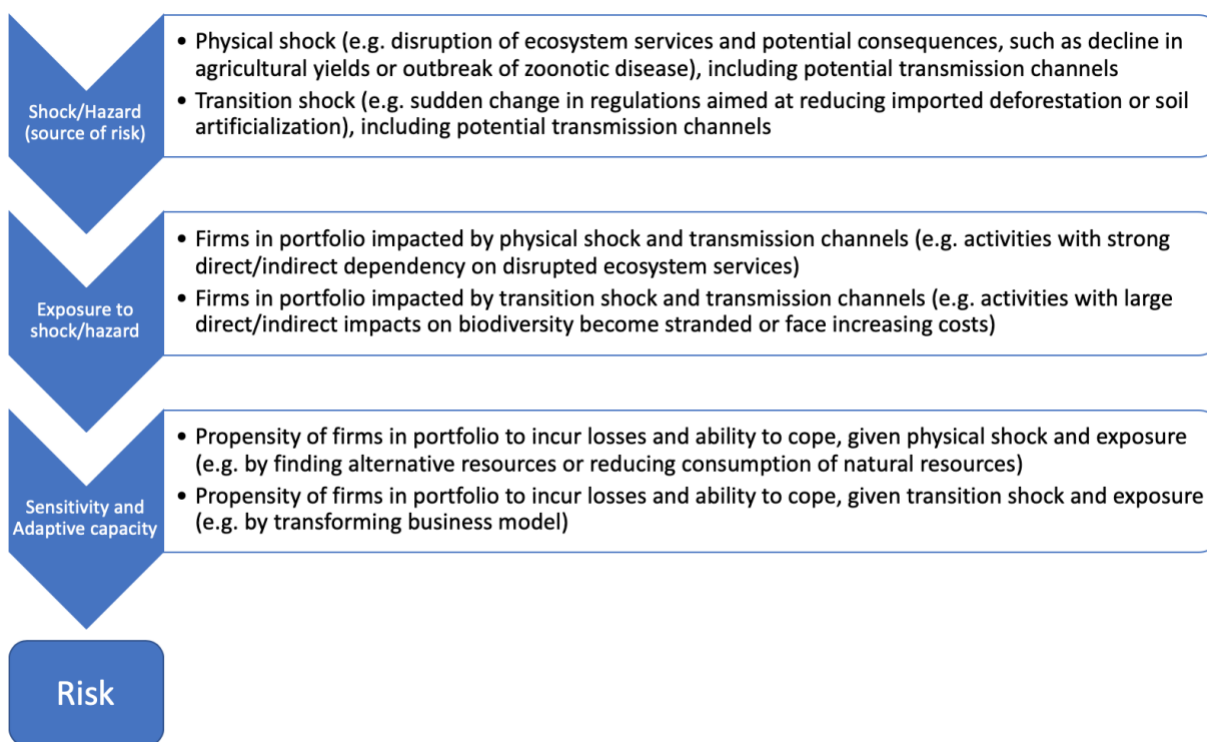
The financial and environmental literatures tell us that in order to conduct a forward-looking assessment of nature-related risks, three components are needed (see Figure 4): (i) a scenario of the hazards or shocks that could translate into financial risks; (ii) metrics of exposure of financial institutions (or the firms in their portfolios) to these hazards/shocks; and (iii) tools to determine the vulnerability of financial institutions, i.e. their sensitivity and adaptive capacity (or that of the firms in their portfolios) given the shock and exposure they face.

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<sup>29</sup> This means that the economic and financial outcomes that could result from current biodiversity-related trends do not lend themselves to probability measurements (Keynes, 1936; Knight, 1921).

<sup>30</sup> Other approaches could be followed, such as a precautionary financial policy framework (Chenet et al., 2021). While this approach may be relevant from a policymaking perspective (see Svartzman et al. (2021) for a discussion), we do not follow it here since the goal of this paper is merely to understand how far it can go in the exploration of BRFR.

Figure 4 – The three steps needed to conduct a biodiversity-related financial risk assessment



*Given the lack of standard biodiversity-related scenarios tailored to the financial system (i.e. lack of clarity on the nature of potential shocks/hazards, step 1 of the Figure) and the lack of tools to assess the vulnerability of economic/financial agents (sensitivity and adaptive capacity of firms in portfolio, step 3) to the scenario, this paper focuses on: (i) metrics of exposure (step 2) to a theoretical shock, assuming that the higher the dependence on ecosystem services and the greater the impacts on biodiversity, the more exposed financial institutions are to physical and transition risks respectively (Sections 4 and 5); and (ii) suggesting avenues for research to better envision potential biodiversity-related hazards, their transmission mechanisms to the financial system, and tools to assess the vulnerability of financial institutions to such scenarios (Section 6).*

However, challenges stand in the way of conducting a full-fledged biodiversity-related scenario analysis:

- First (step 1 in Figure 4), we need to have a clear idea of the type of hazards or shocks that could occur, but these remain uncertain and no ad hoc scenarios have yet been designed for central banks and financial supervisors (unlike for CRFR, with the recent development of climate-related scenarios (see NGFS, 2020)). As a result, both physical and transition sources of risks remain extremely difficult to envision in a systematic manner. Moreover, the multiplicity of metrics relating to biodiversity (meaning among other things that it is difficult to translate them into a single monetary metric such as a universal price on carbon) makes it extremely difficult to design a comprehensive scenario narrative, e.g. to determine how the global loss of biodiversity can impact GDP or how the measures aimed at protecting biodiversity can impact several economic sectors through pricing mechanisms.

- Second (step 2 in Figure 4), once the scenario of hazard or shock is defined, one can try to assess the exposure of agents (whether it be individuals, businesses, financial players or sovereign players) to this transition or physical shock. One can define exposure as being in places and settings that could be adversely affected by the hazard. For example, in the case of a policy shock consisting of the extension of protected areas, the exposure of a given business to this shock depends on whether it has production facilities or suppliers located in the future protected area. However, estimating the exposure of specific agents remains difficult without a clear idea of the hazard, and could require some very specific (e.g. localized) data.
- Third (Step 3 in Figure 4), getting an idea of the risk that emerges from a given hazard and a given exposure requires assessing other aspects of vulnerability to the shock, as exposure to the hazard does not automatically translate into risk. Indeed, once exposed, it is necessary to evaluate agents' sensitivity to the shock (i.e. their propensity to incur losses or be impacted by the shock once exposed), and their ability to cope with these impacts or losses (their adaptive capacity). In our example above, the business will be more sensitive if most of its production facilities are located in future protected areas (which may lead the company to lose a significant proportion of its turnover and its physical assets). However, it may be able to adapt to the shock and reduce losses if its production facilities (buildings, machinery) can be easily moved out of the protected area, or if the company can transform its activity and shift towards a sector that is less damaging to biodiversity. As discussed in Section 6.3, methodologies aimed at assessing the ability of individual firms (or other agents) to adapt to (or align with) specific scenarios are still in their infancy, thereby creating another problem for the assessment of BRFR.

Given the lack of commonly agreed biodiversity-related scenarios and methodologies to measure the vulnerability of individual agents, this paper proceeds as follows:

- In order to approximate physical risks, we build on van Toor et al.'s (2020) use of the ENCORE methodology (Natural Capital Finance Alliance, 2021), to provide a proxy of the direct exposure to physical shocks, by assessing the dependencies of the economic activities financed by French financial institutions on a range of ecosystem services. The rationale is that in the absence of standard scenarios of physical shocks, we can assume that a business that is highly dependent on ecosystem services is more likely to be directly affected by a physical shock (the greater the dependency, the greater the *a priori* exposure to physical risks). The modifications made to the methodology used by van Toor et al. (2020) are explained in the next section.
- In order to approximate transition risks, we also build on van Toor et al. (2020) to provide a measure of the total impacts of the economic activities financed by French financial institutions on biodiversity (i.e. the "biodiversity footprint" of their portfolio). We do so by using the Biodiversity Impact Analytics – Global Biodiversity Score (BIA-GBS) methodology, which builds on the GLOBIO model used by the DNB (van Toor et al., 2020), as explained in the next section. The rationale is that in the absence of standard scenarios of transition shocks, we can assume that a business with a significant negative impact on biodiversity has a higher chance of being affected by a biodiversity transition shock than

a business with a low impact.<sup>31</sup> As the DNB report puts it, the “biodiversity footprint for financial institutions can serve as an indicator for increased transition risks” (van Toor et al., 2020, p. 21).

- Section 6 then suggests three potential avenues for future research that could make it possible to go further into the assessments conducted in Sections 4 and 5, while fully factoring in the challenges underlined in Section 3. These three avenues relate to: (i) the development of biodiversity-related scenarios; (ii) the use of ad hoc methodologies to account for the potential cascading effects of biodiversity-related shocks across sectors (due to their limited or non-substitutability), and their potential contagion effects throughout the financial system; and (iii) the development of biodiversity-alignment methodologies, which could be used in the context of a double materiality perspective.

## 4 Methodology to assess the dependencies and impacts of French financial institutions on biodiversity

This section explains the methodology used to assess how the securities held by French financial institutions’ (that we hereafter call the “portfolio” of French financial institutions) depend on ecosystem services, as well as their impacts (or footprint) on biodiversity. Given the challenges associated with measuring BRFR discussed in Section 3, we argue along with van Toor et al. (2020) that the level of dependency can serve to approximate the exposure of the financial system to physical risks; while the level of impacts can serve to approximate the exposure to transition risks. However, we acknowledge that more work will be needed to translate the methodologies described here and results presented in Section 5 into actual financial risk assessment (as further discussed in Section 6).

The methodology to assess French financial institutions’ dependencies on ecosystem services and impacts (footprint) on biodiversity consists of three main steps (see Figure 5):

- Step 1: Linking securities to their issuer. We first connect the securities held by French financial institutions (the “security holders”) to the companies that issued them (the “security issuers”).
- Step 2: Assessing the dependencies and impacts of each security issuer. We then evaluate each issuer’s<sup>32</sup> dependency on ecosystem services (by means of a “dependency score”), and its biodiversity footprint (using the MSA.km<sup>2</sup> metric).

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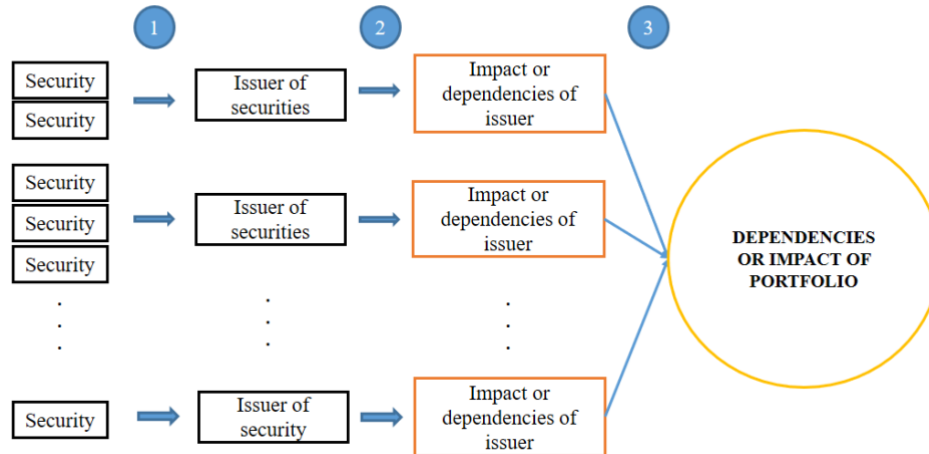
<sup>31</sup> A similar approach has been developed for climate-related financial risks by some financial supervisors. For instance, France’s ACPR (2017) has provided estimates of how it could be exposed to transition risks based on the sectors that had the most significant impacts on climate change. While our approach is similar in this respect, it should be noted that it already provides a comprehensive picture since it accounts for the biodiversity impacts of all economic sectors (not only those that contribute most to biodiversity loss) and it considers Scopes 1, 2 and 3.

<sup>32</sup> It is important to note that while we construct each dependency score and biodiversity footprint at the firm level, the underlying score/footprint is given at the sectoral and regional (except for Scope 1 dependencies) level. See below for more detail.

- Step 3: Assigning the dependencies and impacts of the security issuers to the portfolio. We combine the amount of the securities of each issuer held by French financial institutions with the issuers' dependency scores (respectively, their biodiversity footprints). We thus obtain a dependency score (respectively, a biodiversity footprint) for the total securities portfolio of French financial institutions.

**Figure 5 – Assessing the dependencies and impacts of the French financial system**

Assessing the dependencies and impact of the security held by French financial institutions (the « portfolio »)



In practice, one can use different data and make different hypotheses for each of these three steps. We present two different ways of doing so. Below, we describe the proprietary “Biodiversity Impacts Analytics” (BIA-GBS) methodology, which we use to construct the results presented in this paper. The BIA-GBS methodology was developed jointly by CDC Biodiversité and Carbon4 Finance (C4F), and draws on the Global Biodiversity Score (GBS) developed by CDC Biodiversité. In addition, we propose alternative ways to conduct the analysis in Annex 2.A.

#### 4.1 Linking securities to their issuer (Step 1)

**Data on securities.** The data on the securities held by French financial institutions come from the Securities Holding Statistics by Sector (SHS-S) database.<sup>33</sup> We restrict our sample to three types of securities (listed shares, short-term debt securities and long-term debt securities) issued by French and foreign non-financial corporations (ESA 2010 sector S11) and held by French financial institutions (ESA 2010 sector S12) at the end of 2019. At that time, French financial institutions held EUR 1.11 trillion issued by 15,546 non-financial corporations in France and abroad. We restrict our sample<sup>34</sup> of issuers by taking the 1,443 issuing companies that account for 95% of the

<sup>33</sup> These data are collected quarterly by Eurosystem national central banks (and by a number of other ESCB central banks on a voluntary basis) for all financial institutions; the coverage rate is close to 100%. It covers four types of securities: listed shares, short-term debt securities, long-term debt securities and investment fund shares.

<sup>34</sup> We restrict our sample simply because beyond our ‘95% portfolio sample’, the coverage of sectoral allocation for each firm is not as good.

total value of securities held (this sample is hereafter called the “portfolio” of French financial institutions). The data provide a list of the securities with their ISIN identifiers, the characteristics of the issuing company and the value (position) held in aggregate by French financial institutions, by type of institution.

**Linking securities to their issuer.** The BIA-GBS methodology uses an in-house C4F referential database that links the ISIN identifier of each security with the issuer of the security (see Annex 2.A, Step 1, for alternative method). Eventually, BIA-GBS allows us to cover 94.7% of the market value in the “portfolio” sample, which corresponds to 90% of the total market value of listed shares and debt securities held by French financial institutions.

#### 4.2 Assessing the dependencies and impacts of security issuers (Step 2)

The second step consists in assessing the dependency scores and biodiversity footprint of each of the companies that issued the securities.

**Obtaining the sector and region of the company’s turnover.** The dependency score and the biodiversity footprint of each issuer will depend on the sector and region of the world where production takes place (note that in the case of dependency scores, the region matters only for “upstream dependencies”<sup>35</sup>). Therefore, one first needs to obtain the decomposition of each issuer’s turnover by sector and region. In the BIA-GBS database, this is done by using C4F’s Climate Risk Impact Screening (CRIS) database (see Annex 2.A, step 2, for an alternative method). This proprietary database has been developed by C4F since 2017 to assess climate physical risk. It provides, for each company, the sectoral and geographical breakdown of its turnover. For a company with various sectoral activities in various countries, the footprint and dependency analysis will be run for each of the underlying business segments in each country (creating sector-country pairs) before aggregating the analysis at the company level (see below). These sector-country pairs are built using external financial and corporate data, and by drawing on C4F’s expertise to reprocess these financial data and map company’s segments to their internal sector classification.

**Conversion of sector and region into EXIOBASE3 format.** The tools used to compute dependency scores (ENCORE) and biodiversity footprints (GLOBIO) are combined with a table called EXIOBASE through the GBS (see below). EXIOBASE3 (Stadler et al., 2018) is an open-access EE-MRIO (environmentally extended multi-regional input-output) table that contains 163 industries with a granular decomposition of the agriculture and mining sectors, and 49 world regions with a granular decomposition of European countries. As an MRIO table, it provides information on the value of output produced by each sector in each region, on the type of intermediary consumptions (in value) used to produce this output, and hence on the value chains of each production sector in each region. C4F has built a correspondence table between its CRIS database

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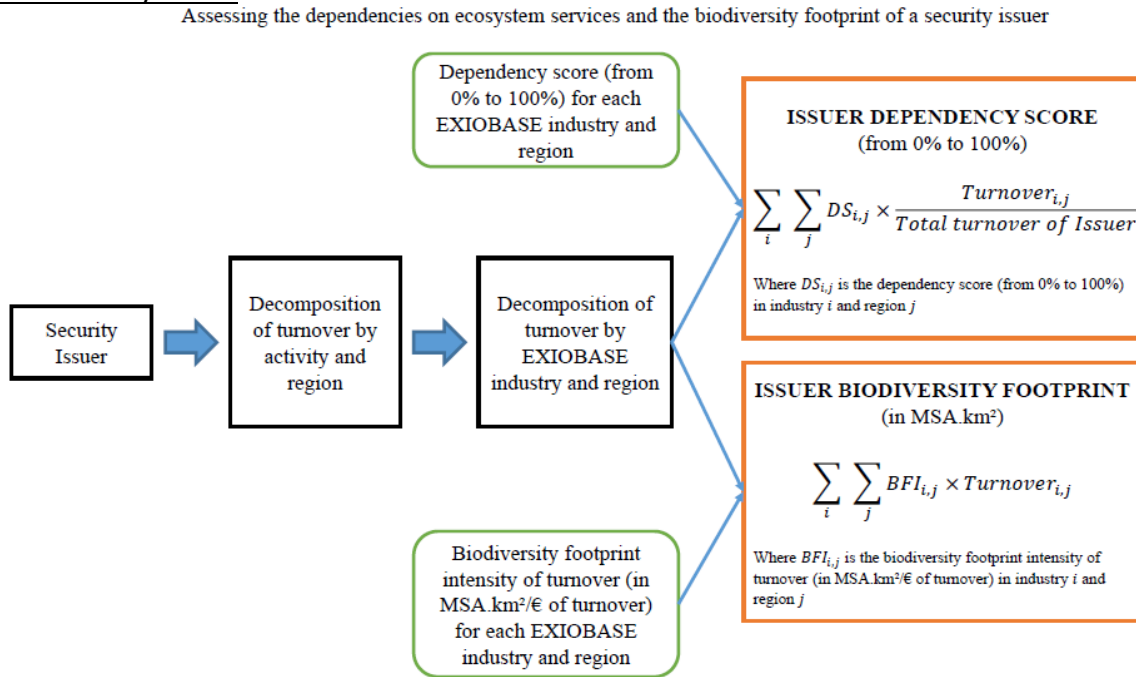
<sup>35</sup> This is because the economic sectors of suppliers can vary from one region to another. The Scope 1 dependency of each economic activity on ecosystem services is however the same across the entire world in the methodology we use.



and the EXIOBASE3 classifications. Thus, the BIA-GBS database converts the CRIS production activities and regions into EXIOBASE3 format so that the turnover of each company, by sector and region, can be plugged into the GBS model (see Annex 2.A, Step 3, for an alternative method).

Once we know the sectors and regions where the company’s turnover comes from, we can assign to the issuer the average dependency score and the biodiversity footprint intensity (per euro of turnover) of its sector-region pair (see Figure 6 and Annex 2.B for more detail on this step).

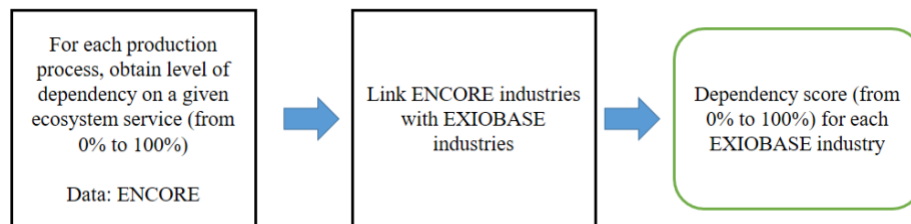
**Figure 6 – Assessing the dependencies on ecosystem services and the biodiversity footprint of a given security issuer**



#### 4.2.1 Computing the issuer’s dependency score

This section describes how a dependency score is obtained for each issuer. We compute the direct (Scope 1) dependency score for each EXIOBASE industry and region by connecting them with the ENCORE database (Figure 7). In addition to these Scope 1 dependency scores, we compute the upstream dependency scores of all sectors, as detailed in Annex 2.C.

**Figure 7 – Assessing the Scope 1 dependency score of a given ecosystem service for each sector-region pair**



**The ENCORE database.** The ENCORE (Exploring Natural Capital Opportunities, Risks and Exposure) database was developed by the Natural Capital Finance Alliance jointly with UNEP-WCMC (see Natural Capital Finance Alliance, 2021). ENCORE assesses the interdependence of 86 types of production processes with 21 ecosystem services, which are themselves related to eight types of natural assets.<sup>36</sup> The 21 ecosystem services are classified according to the Common International Classification of Ecosystem Services (CICES) (see Table 1): 17 of the ecosystem services considered by ENCORE are regulation ecosystem services (16 biotic and one abiotic); the four remaining ecosystem services consist in two biotic provisioning services and two abiotic provisioning services (related to surface water and ground water). ENCORE does not include cultural ecosystem services and other relationships that are linked to more intangible forms of attachment to ecosystems or biodiversity.

Table 1 – Ecosystem services covered by ENCORE

<b>Ecosystem service</b>	<b>Type of ecosystem service</b>
Ground water	Provisioning
Surface water	Provisioning
Genetic materials	Provisioning
Fibers and other materials	Provisioning
Animal-based energy	Provisioning
Mass stabilization and erosion control	Regulation and Maintenance
Climate regulation	Regulation and Maintenance
Flood and storm protection	Regulation and Maintenance
Filtration	Regulation and Maintenance
Dilution by atmosphere and ecosystems	Regulation and Maintenance
Water flow maintenance	Regulation and Maintenance
Water quality	Regulation and Maintenance
Soil quality	Regulation and Maintenance
Pest control	Regulation and Maintenance
Disease control	Regulation and Maintenance
Ventilation	Regulation and Maintenance
Buffering and attenuation of mass flows	Regulation and Maintenance
Bio-remediation	Regulation and Maintenance
Maintain nursery habitats	Regulation and Maintenance
Mediation of sensory impacts	Regulation and Maintenance
Pollination	Regulation and Maintenance

Source: authors, based on Natural Capital Finance Alliance (2021)

To measure the level of direct dependency of each production process on ecosystem services, ENCORE assigns dependency (or materiality) scores. Five dependency scores are available, from Very Low to Very High.<sup>37</sup> The construction of the levels of dependency of each production process

<sup>36</sup> Natural assets are biophysical structures that provide ecosystem services.

<sup>37</sup> For instance, the functioning of the production process “Large-scale irrigated arable crops” depends on the service “Water flow maintenance” (among others) with a High dependency level.

in ENCORE is the product of two factors: the degree of disruption to production processes if the ecosystem service were to disappear, and the expected ensuing financial losses. In ENCORE, the levels of dependency are not regionalized. This means that, for each ecosystem service, a production process occurring in one region is considered to have the same level of dependency as the same production process in another region.

**Linking ecosystem services with economic sectors.** When a business activity (or sector) uses a production process that is dependent on a given ecosystem service, we say that this activity is dependent on this service. ENCORE initially assigns production processes to business activities (sectors) based on the GICS classification. In order to assess the dependency of companies on ecosystem services, the BIA-GBS methodology uses the EXIOBASE3 nomenclature of industries<sup>38</sup> mentioned above. Thanks to a concordance table connecting the 163 EXIOBASE3 industries to the 86 ENCORE production processes, the GBS assigns to all EXIOBASE industries a set of dependency scores, with one for each of the 21 ecosystem services listed by ENCORE. This is done by converting the levels of dependency from Very Low to Very High into percentage scores from 20% to 100% so that they can be aggregated. In order to allocate a unique dependency score (on a given ecosystem service) to a sector (or industry) when the sector depends on several production processes with different levels of dependency, the simple mean<sup>39</sup> of those scores is used:

$$DS_s^e = \sum_{k=1}^n \frac{L_k^e}{n}$$

where  $DS_s^e$  is the (Scope 1) dependency score of sector  $s$  on a given ecosystem service  $e$ , there are  $n$  production processes  $k$  involved in sector  $s$  and  $L_k^e$  is the level of dependency of production process  $k$  to ecosystem  $e$ .

In addition to these Scope 1 dependency scores, we compute the upstream dependency scores of all sectors, as detailed in Annex 2.C. Note that our method of computing upstream dependencies involves us assuming that the total indirect biodiversity impact is a weighted average of the biodiversity impacts of the sectors included in the entire value chain. One could think of different aggregation approaches, such as using the minimum or maximum biodiversity impact observed in the supply chain.

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<sup>38</sup> DNB (2020) also used ENCORE to document an initial mapping of the potential impact of biodiversity loss for the Dutch financial sector. In order to link ENCORE to financial data, the DNB re-classified GICS sectors into the NACE rev.2 nomenclature (rather than EXIOBASE as in our case).

<sup>39</sup> Aggregating the different levels of dependency evaluated for each production process into a single dependency score per sector entails a loss of information. One could decide to use the maximum of the processes' levels of dependency (hence computing a worst-case scenario) or the minimum one (hence taking a conservative approach). We are aware that the mean approach used in this paper is arbitrary and we leave robustness checks using alternative approaches for further studies.

#### 4.2.2 Computing the issuer's biodiversity footprint

We compute a biodiversity footprint intensity of turnover via the BIA-GBS methodology for each (EXIOBASE) industry and region. As explained above, these footprints by sector-region pair are then aggregated<sup>40</sup> to obtain the biodiversity footprint of each of the companies that issued the securities held by French financial institutions (i.e. all companies in the 'portfolio' assessed).

The biodiversity footprint is expressed in MSA.km<sup>2</sup> (see Annex 2.D for more details). The Mean Species Abundance (MSA) is defined as the average abundance of originally occurring species relative to their abundance in the undisturbed ecosystem, understood here as equivalent to a pristine state that is intact and undisturbed by human activity. A loss of x MSA.km<sup>2</sup> is equivalent to the conversion of x km<sup>2</sup> of undisturbed ecosystem (with an MSA of 100%) into a totally artificialized area (MSA of 0%). The loss of MSA.km<sup>2</sup> can be expressed in static or dynamic terms. The static footprint includes all the "persistent effects" that remain over time (or stocks of impacts), while the dynamic footprint includes the changes (or flows) in biodiversity (new biodiversity consumption, restoration or conservation) during the assessment period (e.g. during one year).

**The Global Biodiversity Score® (GBS, see Annex 2.D for more details).** The biodiversity footprint intensity in MSA.km<sup>2</sup>/€ of turnover by sector-region pair (see Figure 8) is derived by the Global biodiversity score® (GBS), developed by CDC Biodiversité. The GBS footprint assessment is conducted in two main steps (building on Wilting & von Oorshot, 2017):

- (1) From a sector-region pair to pressures on biodiversity.** The GBS first assesses the contribution of economic activities to pressures on biodiversity. To do so, (i) the EXIOBASE3 environmentally extended MRIO table converts data on turnover by industry and region into material inputs (uses of commodities, products and water) and emissions of pollutants; (ii) in-house tools developed by CDC Biodiversité convert some of these material inputs into various pressures<sup>41</sup> on terrestrial and aquatic freshwater biodiversity (see Annex 2.D).
- (2) From pressures to impacts on biodiversity.** The GBS then translates these pressures into impacts on biodiversity, expressed in MSA.km<sup>2</sup>, using the impact factors provided by the GLOBIO model (Shipper et al., 2009; Shipper et al., 2016) developed by the Dutch environmental agency (PBL).<sup>42</sup> The IPBES (2019) defines five main pressures on biodiversity: land and sea use change, direct exploitation of organisms, climate change, pollution and invasive species. The GBS partly cover these pressures, both for terrestrial and aquatic biodiversity. However, some pressures like invasive species, unsustainable

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<sup>40</sup> Note that for climate change, the BIA-GBS methodology uses the recalculated GHG emissions of each issuer taken from Carbon Impact Analytics (CIA), an in-house database developed by C4F, instead of taking the EXIOBASE average from the sector-region in which the company operates.

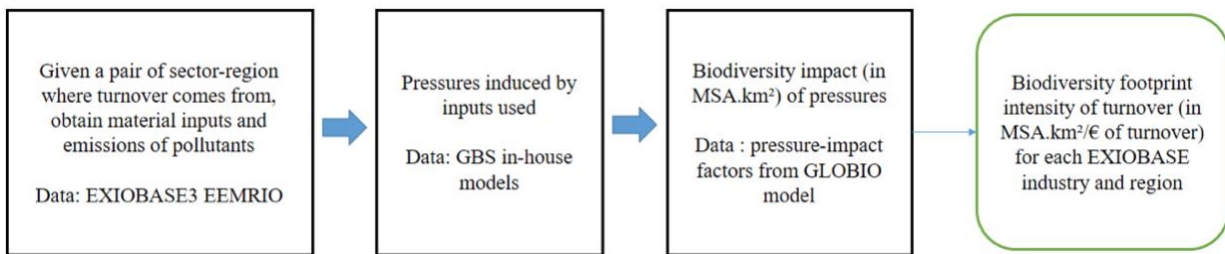
<sup>41</sup> Some of the pressures are directly obtained from EXIOBASE3, without using any in-house tool.

<sup>42</sup> Note: These different steps allow the assessor to use the best data available to be as accurate as possible in the evaluation of impacts. The assessment may start from Step (1) if only financial data are available, from Step (2) if data on material inputs, water use or emissions are provided, or Step (3) if some pressures are known (surface and type of land use, carbon footprint). The BIA-GBS methodology starts from Step (1), except for climate change (the carbon footprint of each company being known thanks to the CIA database).

hunting and fishing, some sources of pollution like plastic, as well as pressures on marine biodiversity more generally, have yet to be included (see Table in Annex 2.D for a comprehensive overview).

**The BIA-GBS methodology and the GBS.** An interesting feature of the BIA-GBS methodology is that, for climate change pressure, it does not use the average greenhouse (GHG) emissions intensity of turnover in the sector-region pair in which the company operates that would be obtained with EXIOBASE. Instead, it uses recalculated GHG emissions for each issuer, taken from an in-house database developed by Carbon4 Finance called Carbon Impact Analytics (CIA), which makes it possible to obtain a biodiversity footprint that is more accurate for each company. The CIA database provides Scope 1, 2 and 3 GHG emissions. They are obtained with a bottom-up approach, by collecting physical output data (published by companies in their annual, financial or environmental reports) and translating it into tons of CO<sub>2</sub>.

Figure 8 – Assessing the biodiversity footprint intensity of turnover for each sector-region pair



*NB: BIA adds information on individual companies' GHG emissions (from the CIA database) instead of using the average GHG emissions of the company's section/region*

**Computing the upstream biodiversity impact of sectors.** The biodiversity impacts along the upstream value chain of a sector are computed using the classic Leontief inverse matrix (or “matrix of technical coefficient”) obtained with the EXIOBASE regionalized input-output table. The Scope 1 biodiversity footprint intensity of sectors-regions is compiled in a direct footprint matrix  $D^{BFI}$ , taking regions in its 49 rows and sectors in its 163 columns. We compute the matrix  $U^{BFI}$  of “total upstream biodiversity footprint intensities” using the matrix of total requirements coefficients (Leontief inverse,  $L^{-1}$ ):

$$U^{BFI} = D^{BFI} \times (L^{-1} - I)$$

The Scope 3 impact resulting from climate change pressure is directly obtained by using the CIA database of GHG emissions.

#### 4.3 Assigning the exposure of security issuers to the portfolio (Step 3)

**Assigning the companies' dependency scores to the portfolio.** We compute the portfolio's dependency score (for a given ecosystem service) by weighting the dependency scores (for a given ecosystem service) of the different security issuers by the share represented by the issuers in the portfolio (in terms of market value of securities held). Let  $i$  denote the companies that

issued the securities in portfolio p,  $DS_i^e$  the Scope 1 dependency score of issuer i on ecosystem service e (or, alternatively,  $U_i^e$ , the upstream dependency score of issuer i on ecosystem service e), and  $amount\ securities_i^p$  the market value of securities issued by i and held in portfolio p. The biodiversity footprint of the portfolio,  $DS_p^e$ , writes:

$$DS_p^e = \sum_i DS_i^e \times \frac{amount\ securities_i^p}{total\ amount\ securities^p}$$

where  $total\ amount\ securities^p = \sum_i amount\ securities_i^p$

We therefore obtain  $m$  dependency scores for the portfolio, one for each of the  $m$  ecosystem services.

**Assigning the companies' footprint to the portfolio** (see Figure 9). We assign only a share of the biodiversity footprint of security issuers to the security itself. This share is defined as the market value of securities held in the portfolio of French financial institutions, divided by the enterprise value of the security issuer (i.e. the share of the issuer's enterprise value that is held in the portfolio). Let i denote the companies that issued the securities in portfolio p,  $BF_i$  the biodiversity footprint of issuer i and  $amount\ securities_i^p$  the value of securities issued by i and held in portfolio p. The biodiversity footprint of the portfolio,  $BF_p$ , writes:

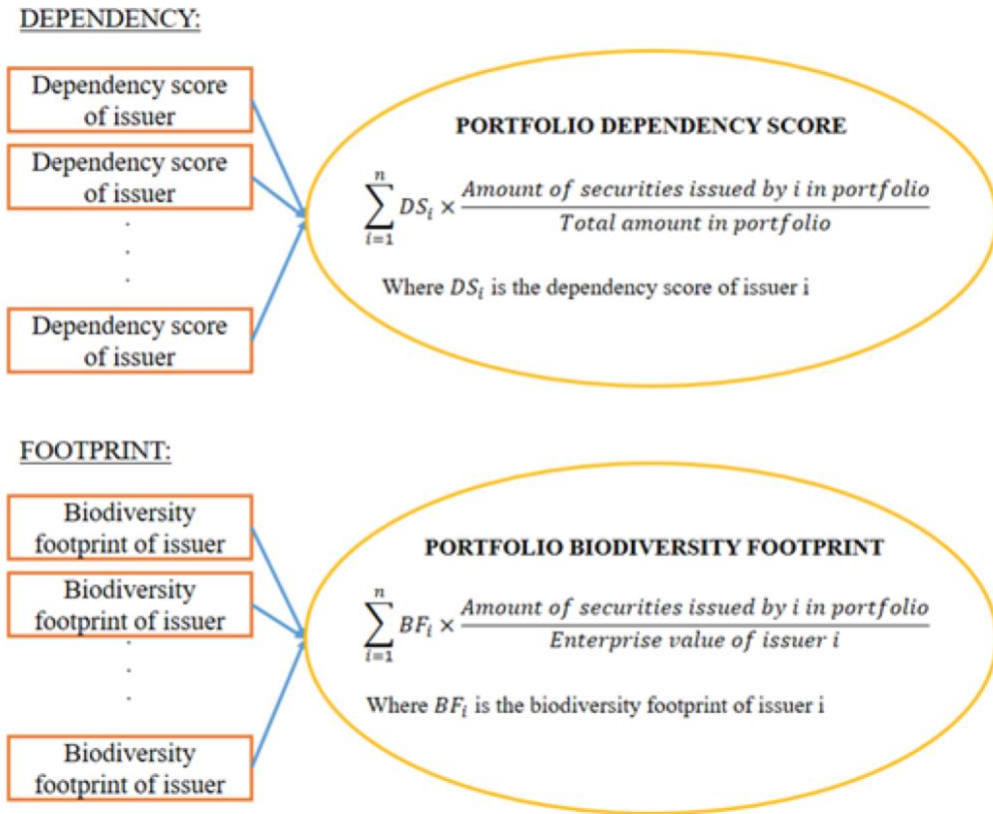
$$BF_p = \sum_i BF_i \times \frac{amount\ securities_i^p}{enterprise\ value_i}$$

In BIA-GBS, the enterprise value is obtained from the company's annual report and/or from an external financial data provider. Note that our allocation rule differs from that of the DNB (van Toor et al., 2020), which uses the market capitalization – rather than the enterprise value – of firms to assign a share of the biodiversity footprint to the portfolio. We prefer to use the enterprise value<sup>43</sup> because this allows us to account for the footprint of non-listed firms, including but not limited to large state-owned enterprises. In addition, we consider that from a theoretical perspective, it makes sense to attribute the biodiversity footprint of a firm to all the holders of the securities issued by the firm, rather than to its shareholders only. In this sense, our methodological approach remains incomplete insofar as it does not consider the loans granted by French financial institutions to non-financial corporations. The latter was left out of this study due to lack of access to reliable data, but we consider that further work should be conducted in this respect.

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<sup>43</sup> The *enterprise value* is computed by adding the market capitalization of equity shares to the market *value* of debt and minority interests (investment in another company). From this, the total cash and cash equivalents are subtracted to arrive at the *enterprise value*.

Figure 9 – Computing the portfolio’s dependencies on ecosystem services and biodiversity footprint



## 5 Dependencies and impacts of the French financial system on biodiversity and ecosystem services

### 5.1 Dependencies of the French financial system on ecosystem services

The dependencies of French financial institutions (i.e. their ‘portfolio’ of securities) on various ecosystem services provide useful insight into their potential direct and indirect exposures to physical biodiversity-related shocks.

Considering the Scope 1 dependencies to ecosystem services, i.e. the dependencies of direct operations, we find that 42% of the value of securities held by French financial institutions comes from issuers that are highly or very highly dependent on at least one ecosystem service, and 9% comes from issuers that are very highly dependent on at least one ecosystem service. These results are consistent with those found in previous research for other financial portfolios.<sup>44</sup> We

<sup>44</sup> For example, van Toor et al. (2020) find that 36% of the value of listed shares held by Dutch financial institutions are highly or very highly dependent on one or more ecosystem service. Even though this work makes different methodological assumptions than ours, the results have the same order of magnitude.



find that the portfolio mainly depends on the ecosystem services related to the provision of water (Surface water, Ground water) and on the “maintenance and regulation” type of ecosystem services such as Mass stabilisation and erosion control, Flood and storm protection and Climate regulation.

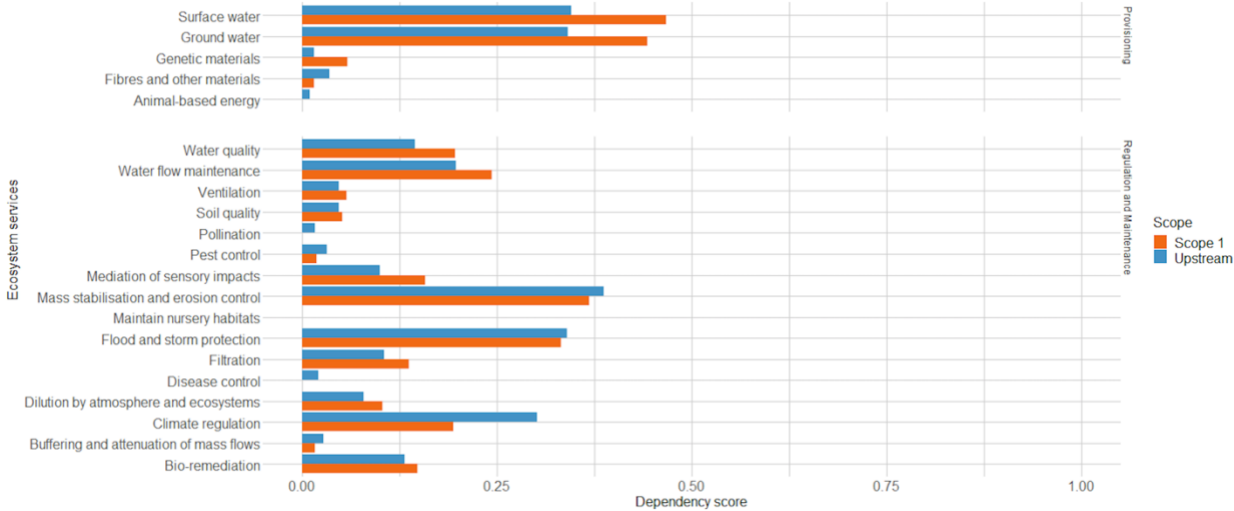
Considering the upstream dependencies on ecosystem services, we find that all issuers are at least slightly dependent on all ecosystem services through their value chains. Considering both the Scope 1 and upstream dependencies, we find that some issuers that rely directly or indirectly on agricultural production (e.g. the manufacturing of food and beverages) tend to be dependent on many ecosystem services.

In what follows, we present: (i) the score of the total French portfolio, which aggregates all French financial institutions’ portfolios (ii) the disaggregation of the score by ecosystem service; (iii) the disaggregation of the score by economic sector.

5.1.1 Total portfolio dependency scores

We find that Scope 1 dependency scores differ greatly depending on the ecosystem service considered (Figure 10.A). The largest dependency score of the portfolio is found for Surface water and Ground water (between 40 and 50%), which would indicate a medium dependency of the portfolio on average. This is because many production processes are dependent on water in the ENCORE database, in particular the production processes primary and secondary sectors rely on, and a large proportion of the security issuers in the portfolio belong to secondary sectors.

Figure 10.A – Scope 1 and upstream dependency scores of the security portfolio of French financial institutions



Overall, we obtain low or medium *average* dependency scores for the portfolio, which we explain by various ‘methodological’ reasons. In particular, when computing the Scope 1 dependency scores of sectors to which issuing companies belong, we chose to use the average level of dependencies of the production processes used for production in the sector (see Section 4.2.1).

The implicit assumption is that there is a possibility for substitution between production processes rather than a complementarity between them. Take for example a sector that relies on various production processes. If only one production process is highly dependent on an ecosystem service *e*, the remaining production processes with a low dependency on *e* will tend to mitigate the dependency of the whole sector on *e*. Hence, if ecosystem *e* were to collapse,<sup>45</sup> our assumption leads to the conclusion that the impact on the overall production of the sector might be moderate, while in reality, the low substitution between production processes in the production process could greatly affect the production of the sector. An alternative assumption could be to assign to the sector the highest dependency level of the business processes it uses, rather than the average.<sup>46</sup>

We also find that some Scope 1 dependency scores are null for pollination, animal-based energy and disease control. The main reason for the absence of direct dependency to these ecosystem services is that the primary sectors, which rely heavily on these ecosystem services, represent a small share of GDP in France, and therefore of financial institutions' balance sheets (moreover, agricultural activities are often financed by bank loans rather than securities, which are the focus of our study). This confirms the fact (discussed in Section 3.2) that if we are to account for physical BRRF (e.g. potential impacts of food disruptions through value chains), we cannot rely entirely on direct dependencies.

Some of the limitations of a Scope 1 approach are partially overcome when looking at upstream dependencies (Figure 10.A): the portfolio is at least slightly dependent on all ecosystem services (e.g. the portfolio becomes slightly dependent on pollination, animal-based energy and disease control). The upstream dependencies on the three most important Maintenance and regulation services (i.e. Mass stabilization and erosion control, Flood and storm protection, and Climate regulation) appear to be higher than Scope 1 dependencies, in particular for Climate regulation. This suggests that the intermediate suppliers of companies issuing the securities in the portfolio are significantly dependent on these ecosystem services.

One might have expected the upstream dependency scores to be higher than Scope 1 dependency scores as they incorporate the dependencies of suppliers, which are likely to be higher when we get closer to primary sectors like agriculture, fibres, timber or mining. The methodology we propose in this paper to compute upstream dependency score however mitigates such patterns. The upstream dependency is indeed a weighted average of each sectoral dependency score, indicating that a high dependency for one sector in the supply chain might be lessened by low dependencies of other sectors (see more in Annex 2.C).

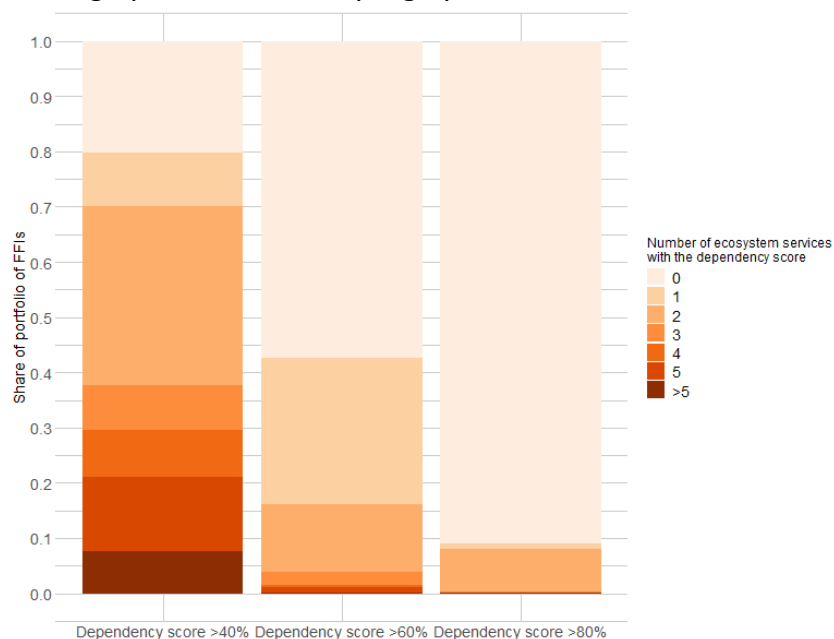
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<sup>45</sup> In reality, note that given the interconnections in the functioning of ecosystems, the degradation of biodiversity is not likely to result in the deterioration of only one ecosystem service *ceteris paribus*.

<sup>46</sup> Another reason for the overall rather low average dependency scores of the portfolio is that ENCORE considers that only a few sectors are dependent on some "regulation and maintenance" ecosystem services (e.g. disease control). However, one could argue that these services are necessary for a much larger range of activities (e.g. tourism, trade, etc.) rather than only for specific activities in the primary and secondary sectors.

In fact, Figure 10.B suggests that a significant amount of the portfolio could be affected by the disruption of specific ecosystem services. We find that 70% of the amount in the portfolio are issued by companies that are at least Moderately dependent (dependency score > 40%) on at least two ecosystem services (cf. first bar in Figure 10.B). More importantly, 42% of the amounts in the portfolio are issued by companies that are at least Highly dependent (Dependency score >60%) on at least one ecosystem service (second bar), and 9% are Very Highly dependent (Dependency score >80%) on at least one ecosystem service (third bar).

**Figure 10.B – Share of the portfolio dependent (through Scope 1) on  $n$  ecosystem services at least Moderately, at least Highly and at least Very Highly**



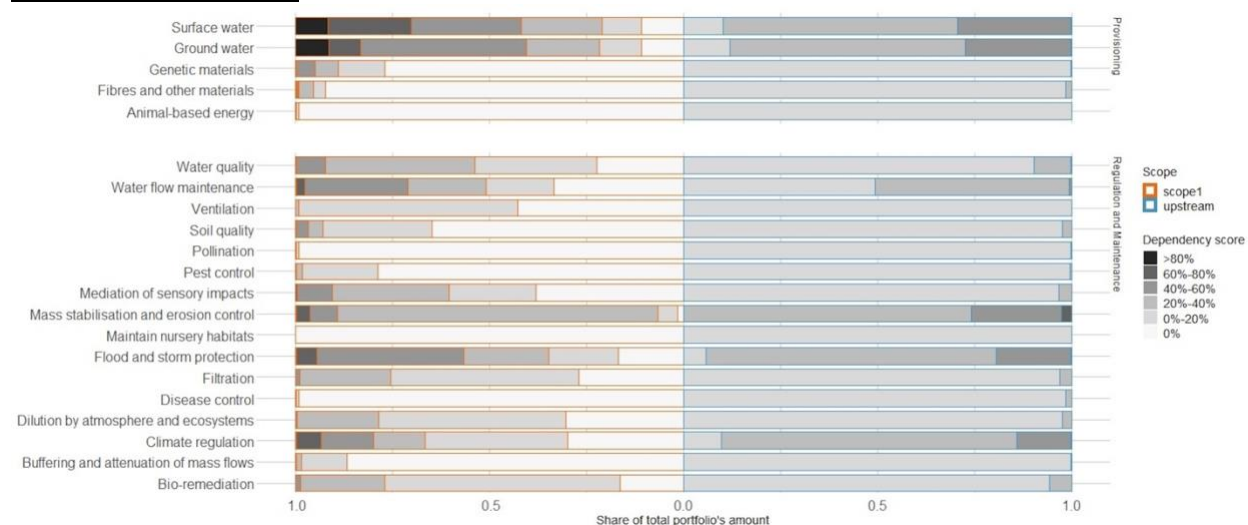
*Note: the bottom of the first column indicates that approximately 8% of the market value of securities in the portfolio of French financial institutions were issued by companies that are at least Moderately dependent (dependency score >40%) on more than five ecosystem services.*

### 5.1.2 Disaggregation by ecosystem service

The question remains whether the high dependency scores within the portfolio can be explained by a few specific ecosystem services or whether they are dispersed among several. From the left-hand side of Figure 11, we can see that Scope 1's Very High dependency scores (>80%) are concentrated on two ecosystem services: Surface water and Ground water. This suggests that, if these ecosystem services were under threat, the situation would likely result in substantial disruption of production processes relying upon them and potentially high exposure and vulnerability of the portfolio to the shock. This high dependency on water is consistent with other studies, notably a report written by Delannoy (2016) for the French Ministry of Ecology, which concluded that water was the ecosystem service 'used' by the greatest number of French economic sectors.

Looking at the distribution of the upstream dependency scores (right-hand side of Figure 11), we find that all securities in the portfolio are issued by companies that are at least slightly dependent on all ecosystem services through their value chains. However, we no longer observe Very High upstream dependency scores, as was the case with Scope 1. This is again due to our methodology, which takes the weighted mean of the dependency scores of all suppliers in the supply chain (see Annex 2.C). This tends to bring the upstream dependency score closer to the average dependency score of 50%, i.e. it ‘attenuates’ High dependency scores and ‘amplifies’ the Low dependency scores of suppliers. As mentioned above, an alternative way to proceed would be to use the minimum or maximum biodiversity impact observed in the supply chain rather than taking the average.

**Figure 11 – Distribution of Scope 1 (left) and upstream (right) dependency scores in the portfolio, by ecosystem services**



*Note: the orange box at the top of the left-hand side of the chart indicates that about 5% of the market value of securities in the portfolio were issued by companies that are Very Highly dependent (Dependency score >80%) on the ecosystem service “Surface water”.*

### 5.1.3 Sectoral disaggregation

The dependency scores of securities in the portfolio ultimately come from the dependency scores of the companies that issued these securities. The dependency scores of companies mainly come from the sector in which they operate.<sup>47</sup> Therefore, understanding where the portfolio dependencies come from involves looking at the dependency score of the sectors to which the companies in the portfolio belong.

<sup>47</sup> Even though the upstream dependency scores also include a regional dimension. Indeed, they take into consideration the value chain of sectors, which can differ depending on the region where production takes place.

Figure 12.A shows the portfolio's sectoral concentration by sector code<sup>48</sup> (the complete table of correspondence between sector codes and names can be found in Annex 2.F). The French financial system is particularly exposed to the following sectors: Chemicals production (i.24.4), Post and telecommunications (i64), Manufacture of medical, precision and optical instruments, watches and clocks (i33), Real estate activities (i70), Other service activities (i93) and Manufacture of beverages (i15.j). The two following heat maps illustrate the dependency score of each sector to each ecosystem services. Looking at Scope 1 dependencies (Figure 12.B), we see that among these main sectors in terms of portfolio concentration, only the Manufacture of beverages (i15.j) has a Very High dependency score on two ecosystem services (Surface water and Ground water). We also see that all sectors are at least Moderately dependent on these two ecosystem services, in particular the agricultural sectors (i01.h and i01.l are Very Highly dependent), the sectors related to mining and quarrying (from i13.1 to i14.3, Highly dependent) and the sectors related to food processing (from i15.c to i15.j, Very Highly dependent).

Overall, the sectors with the more numerous and higher dependencies appear to be the agricultural sectors (i01.h, cultivation of crops, and i01.l, breeding of animals for meat), the food processing sectors, the Collection, purification and distribution of water (i41) and Wastewater treatment (90.5.b). French financial institutions however have relatively low exposures to these sectors (Figure 12.A). Finally, we find that paying attention to upstream dependencies is important<sup>49</sup> (Figure 12.C). This seems particularly true for sectors related to Food processing (from i15.c to i15.j), whose value chain appears to be on average at least slightly dependent on all ecosystem services. This may be due to their reliance on agricultural inputs, whose direct operations (Scope 1) are themselves very dependent on several ecosystem services.

It is noteworthy that ENCORE scores indicate potential, not actual, dependencies. These scores thus only serve to inform initial screening, which should be followed by spatially explicit, company-specific and context-specific assessments of physical risks. The ways in which specific dependencies translate or not into financial risks depend on several factors such as which ecosystem services become disrupted and how they impact other sectors throughout value chains. Macroeconomic modeling of such impacts is in its infancy (e.g. Johnson et al., 2021), and no scenarios of shocks and/or transmission channels are available for the purpose of financial risk assessment. Such issues are therefore discussed further in Sections 6.1 and 6.2.

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<sup>48</sup> This chart is built as follows: when French financial institutions hold x€ of securities in company c, and if the company operates in various sectors, we allocate to sector s the amount invested in proportion to the turnover of company c that comes from sector s. Therefore, the sum of all the amounts in Figure 12.A is equal to the total amount of the portfolio of French financial institutions (there is no double counting). For ease of reading, the chart does not include many sectors for which there is no exposure (e.g. many subsectors in the agricultural sector are not included).

<sup>49</sup> The reader may have noticed from the description of the methodology that there are in fact numerous upstream dependency scores for each sector, as the upstream dependency score also depends on the region where production takes place. Indeed, because for a given sector the value chain varies by region, the sectoral composition and hence the dependency score of the value chain differs from region to region. This chart is built by aggregating the different regional upstream dependency scores for each sector. We use a weighted sum where the weights for region r and sector s correspond to the share of turnover made by companies in the portfolio in region r and sector s, divided by the total turnover made by companies in the portfolio in sector s.

Figure 12.A – Securities in the portfolio, by sector

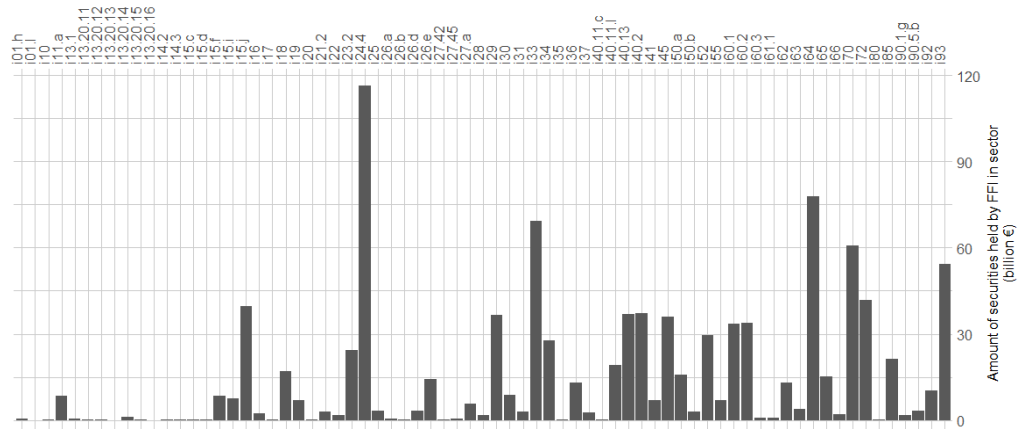


Figure 12.B – Scope 1 dependency scores by sector and ecosystem service

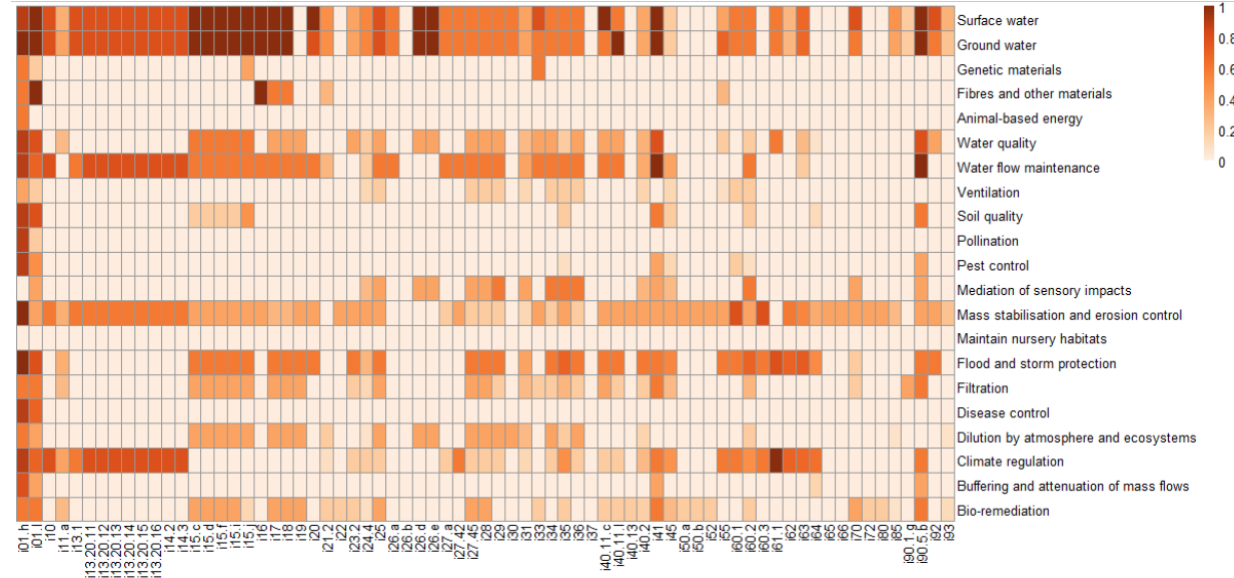
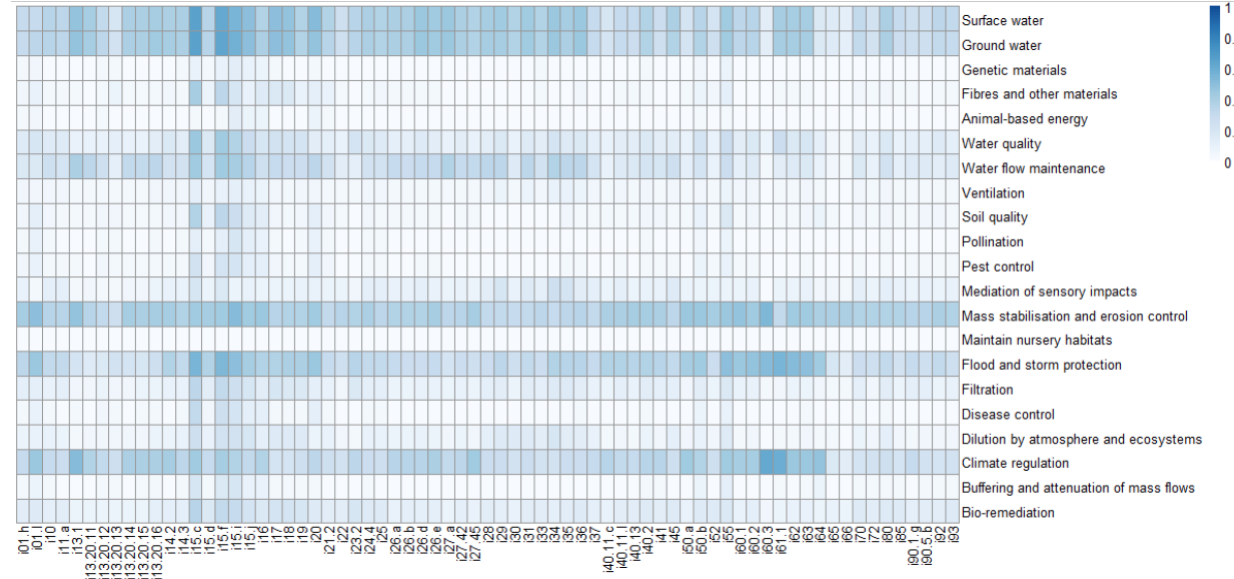


Figure 12.C – Upstream dependency scores by sector and ecosystem service



## 5.2 Impacts of the French financial system on biodiversity

The biodiversity footprint, or “impact”, of French financial institutions (i.e. of their ‘portfolio’ of securities) provides a useful insight into potential direct exposure to transition biodiversity-related shocks. In what follows, we focus exclusively on the impacts on terrestrial biodiversity.<sup>50</sup> Impacts on freshwater biodiversity are treated separately<sup>51</sup> in Annex 2.E, and impacts on marine biodiversity are not covered by the model used.

We find that the accumulated (or static) terrestrial biodiversity footprint of the French financial system is comparable to the loss of at least 130,000km<sup>2</sup> of pristine nature, which corresponds to the complete artificialization of 24% of the area of metropolitan France.<sup>52</sup> The biodiversity ‘intensity’ of the portfolio is 0.13 MSA.km<sup>2</sup> per million euro of securities held. This means that on average, one million euro of securities from the portfolio of French financial institutions has a footprint that is comparable to the complete loss of 0.13km<sup>2</sup> of pristine nature (16 football pitches of 8,000m<sup>2</sup> each).<sup>53</sup> Land use change is by far the main pressure explaining these results. Several economic sectors contribute to the footprint, including chemicals production, processing of dairy products and manufacture and distribution of gas.

Moreover, the portfolio of French financial institutions has an additional annual impact (or dynamic impact) on terrestrial biodiversity that is equivalent to the loss of 4,800km<sup>2</sup> of

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<sup>50</sup> Note that the impacts due to ecotoxicity pressure are not considered.

<sup>51</sup> This is because impacts on terrestrial and aquatic biodiversity cannot be simply aggregated.

<sup>52</sup> The footprint we compute does not exclude potential double counting of the impacts. Indeed, the Scope 1 impacts of a given ‘firm A’ can be partly counted twice in the portfolio’s footprint through the Scope 3 of its supplier ‘firm B’. However, one reason why the extent of double counting may be rather limited in the results presented here is that the portfolio of French financial institutions is mainly made up of securities issued by companies in secondary sectors, while primary sectors such as agriculture (which tend to have the most important Scope 1 footprints, as discussed below) are almost absent from the portfolio. This reduces the chance of having both the company and its raw materials supplier in the portfolio. Indeed, it means that the agricultural sector contributes to our results through the Scope 3 of other firms (mostly in the secondary sector), but almost not at all through their own Scope 1.

In addition, although double counting may be an issue when assessing the ‘responsibility’ of French financial institutions in the decrease in biodiversity (as impacts may be inflated by double counting in the portfolio), it is not necessarily a problem when adopting a risk perspective. Indeed, transition shocks may affect companies in the portfolio directly (due to their Scope 1 impacts) but also indirectly (due to the impact of their suppliers on biodiversity). Accounting both for the Scope 3 and Scope 1 impacts of companies in the portfolio could therefore become important, even if they may be redundant.

<sup>53</sup> Overall, these results are consistent with those obtained for the listed shares portfolio of Dutch financial institutions. Indeed, the DNB (van Toor et al., 2020) finds a biodiversity footprint that is comparable to the loss of 58,000 km<sup>2</sup> of pristine nature, and a corresponding average biodiversity “intensity” of 0.18 MSA.km<sup>2</sup> per million euro in the portfolio (as the size of the portfolio under scrutiny is EUR 320 billion). The difference with our results in terms of intensity may be explained by (i) the different types of securities and issuers considered (we look at debt securities in addition to listed shares, and we focus on non-financial issuers while the DNB considers both financial and non-financial issuers); (ii) the fact that the impacts measured by the DNB are time-integrated while we make a distinction between static and dynamic footprints; and (iii) the fact that our static impact does not include the impacts due to climate change, while they are included in the DNB’s results (which may be the main reason for the higher biodiversity intensity).



‘untouched’ nature, corresponding to an annual complete artificialization of 48 times the area of Paris. Climate change is the main pressure explaining this finding. Several economic sectors contribute to this footprint, including chemicals production and petroleum refinery.

In what follows, we present in more depth the static and dynamic impacts on terrestrial biodiversity.

### 5.2.1 Static footprint

The main drivers of the static footprint of the portfolio are land use and land-use-related drivers of biodiversity loss, or pressures (Figure 13.A). Note that climate change is not yet included as a static pressure on biodiversity in the BIA-GBS methodology due to the difficulty in allocating past greenhouse gas (GHG) emissions to different sectors and regions. As climate change is a major driver of biodiversity loss (although not the biggest one at the world level), one should keep in mind that the static biodiversity footprint presented here is likely to be underestimated, although climate change is included as a dynamic pressure (as set out below).

Figure 13.B shows that most of the footprint comes from upstream activities, in particular from direct suppliers (“Tier 1”), which represent 42% of the total footprint. This may be because a large share of the value of securities held by French financial institutions comes from companies with manufacturing and processing activities (secondary sectors). Companies in such sectors (e.g. food processing) do not necessarily use much land in their production process, but tend to rely on inputs that themselves exert substantial land-use pressures on biodiversity (e.g. crops or cattle). The absence of the “climate change” pressure mentioned above may also explain why the impact of Scope 1 is relatively small.<sup>54</sup>

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<sup>54</sup> For instance, as the direct operations (Scope 1) of manufacturing activities tend to be rather carbon-intensive, accounting for the “climate change” pressure on biodiversity would likely increase the contribution of Scope 1 to the overall footprint. This is nevertheless simply a hypothesis, which has not been tested.

Figure 13.A – Static terrestrial biodiversity footprint of portfolio, by pressure

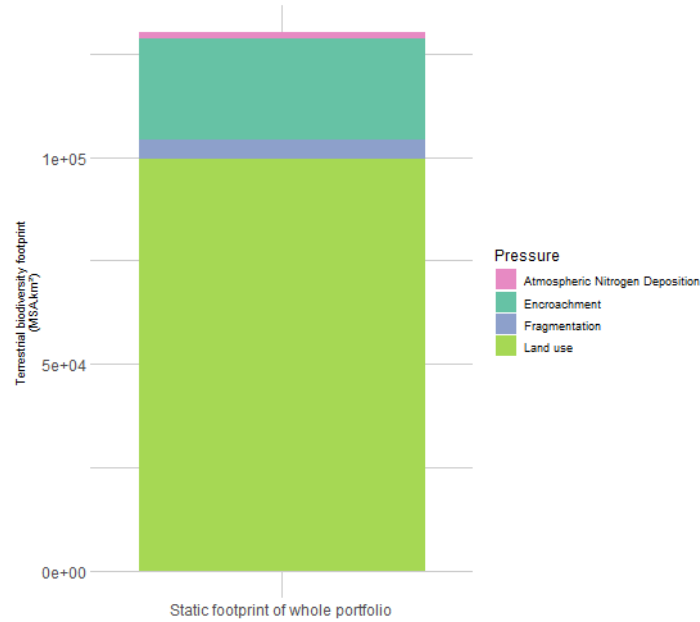
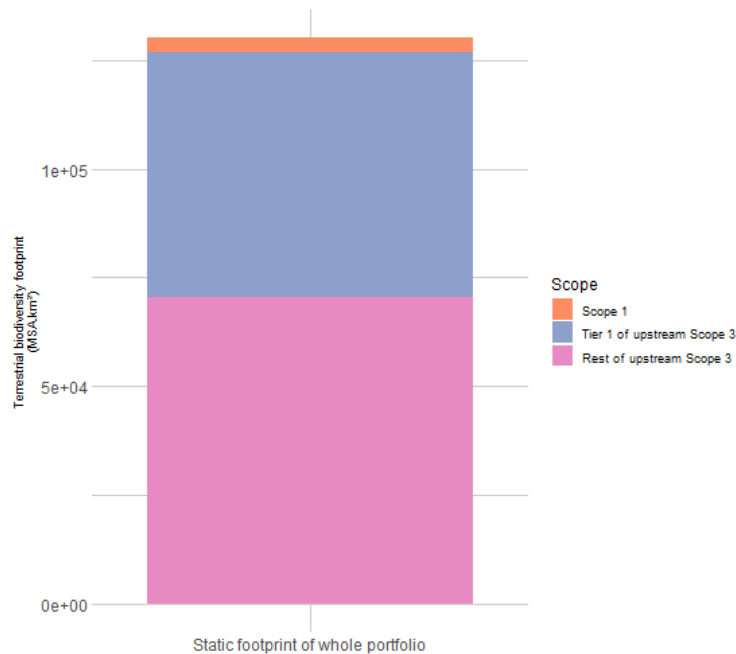


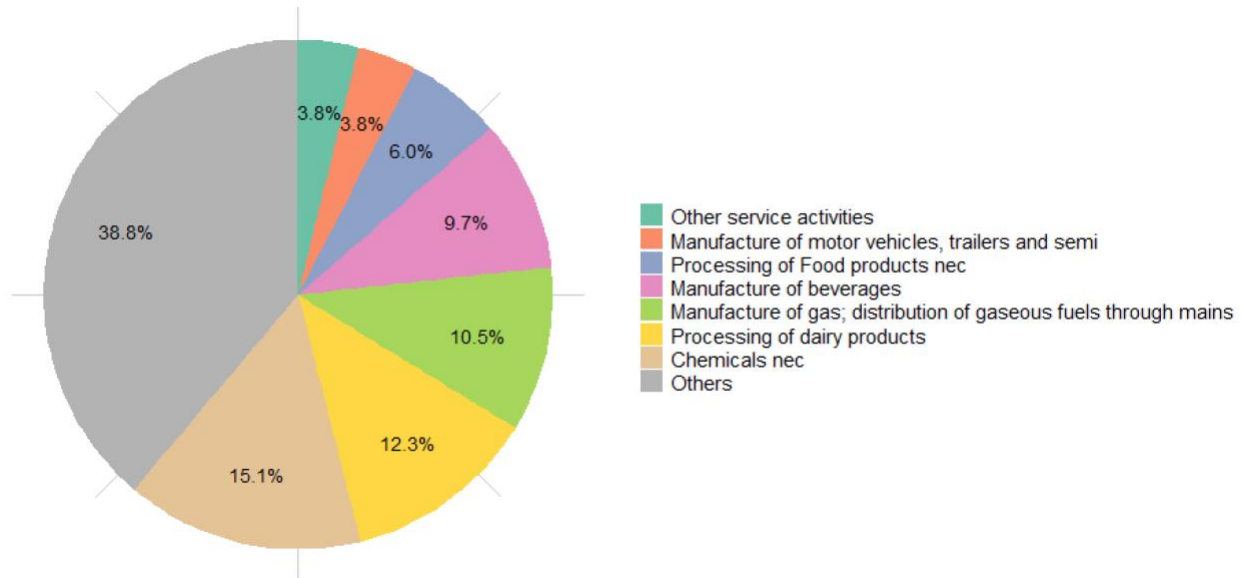
Figure 13.B – Static terrestrial biodiversity footprint of portfolio, by scope



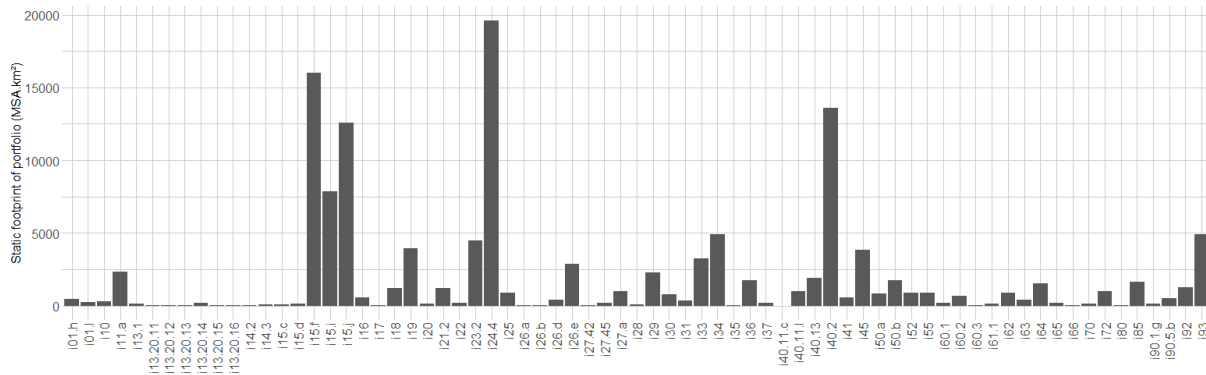
We find that the static impacts of the portfolio mainly come from a few sectors (Figure 14.A for a breakdown by sector and Figure 14.B for the absolute footprint corresponding to each sector). Chemicals production (sector i24.4 in Figure 14.B), processing of dairy products (i15.f), manufacturing and distribution of gas (i40.2), manufacturing of beverages (i15.j) and processing of food products (i15.i) represent more than half of the total static biodiversity

footprint of the portfolio (the complete table of correspondence of industry codes can be found in Annex 2.F).

**Figure 14.A – Breakdown of static terrestrial biodiversity footprint of portfolio, by sector**



**Figure 14.B – Static terrestrial biodiversity footprint corresponding to each sector in portfolio (MSA.km<sup>2</sup>)**

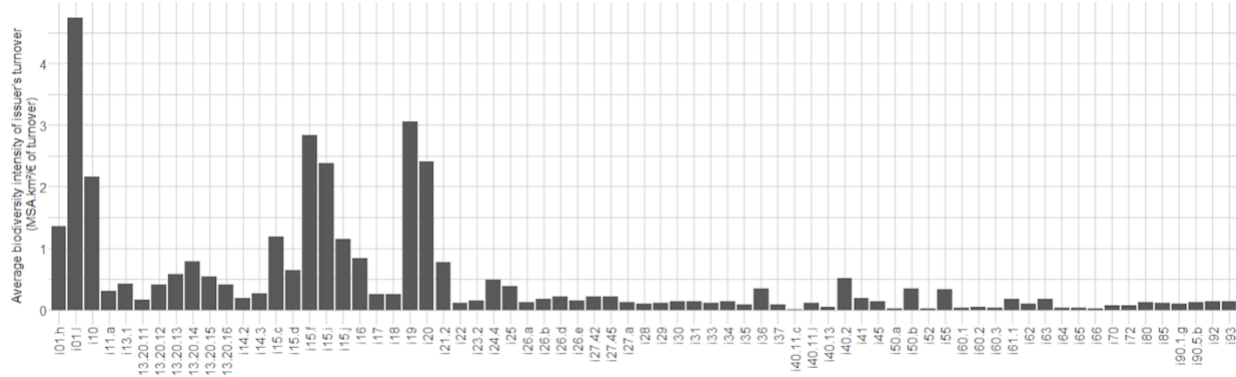


Several factors can explain these results. The most obvious one is that production in these sectors (and/or in the sectors of their suppliers) has particularly large static impacts on biodiversity because they have ‘consumed’, fragmented and encroached on natural areas. In the case of food processing (including processing of dairy products (i15.f), manufacturing of beverages (i15.j) and processing of food products (i15.i)), the production of one euro of turnover for companies in the portfolio that belong to these sectors has a particularly high static biodiversity footprint (Figure 15.A).

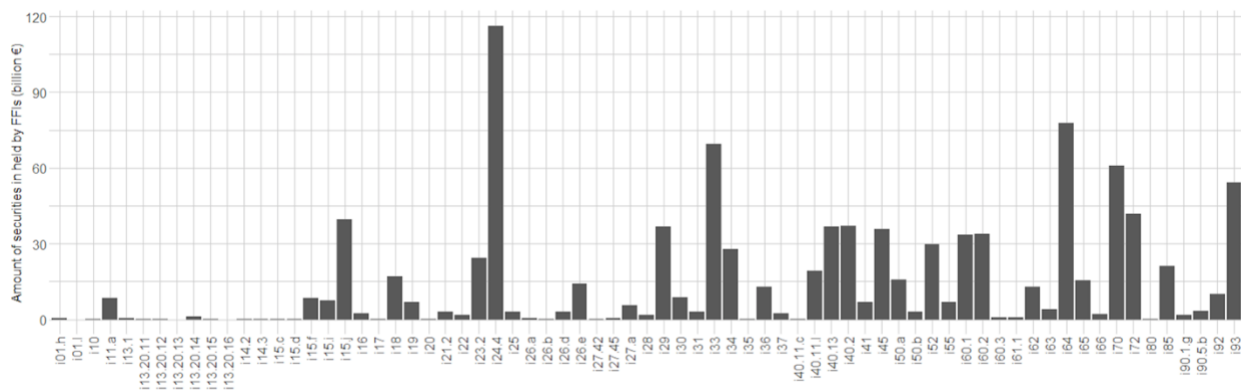
However, the production of one euro of turnover for companies in the sectors of chemicals production (i24.4) and manufacturing and distribution of gas (i40.2) does not appear to

have a particularly high static impact on biodiversity (Figure 15.A). Rather, the large contribution of these sectors to the portfolio’s footprint seems to come mainly from their importance in the portfolio of French financial institutions (Figure 15.B): 11.7% of the securities held in the portfolio come from the chemicals sector and 3.7% from the manufacturing and distribution of gas sector.

**Figure 15.A – Average terrestrial and static biodiversity footprint intensity of turnover by sector, for issuers in portfolio of French financial institutions (MSA.km<sup>2</sup>/M€ of turnover)**



**Figure 15.B – Amounts of securities (billion €) in portfolio of French financial institutions, by sector**



### 5.2.2 Dynamic footprint

The dynamic footprint corresponds to the additional impact on biodiversity each year. We find that 86% of new impacts on terrestrial biodiversity come from climate change, while the rest mostly comes from land use (Figure 16.A). As “climate change” pressure is included in the dynamic analysis and because most of the securities in the portfolio are issued by companies in the manufacturing or processing sectors, we find in Figure 16.B that the contribution of Scope 1 is substantial, in particular when compared with the static impact, which does not account for climate change. However, most of the dynamic footprint comes from direct suppliers (Tier 1 of upstream Scope 3).

Figure 16.A – Dynamic biodiversity footprint of portfolio, by pressure

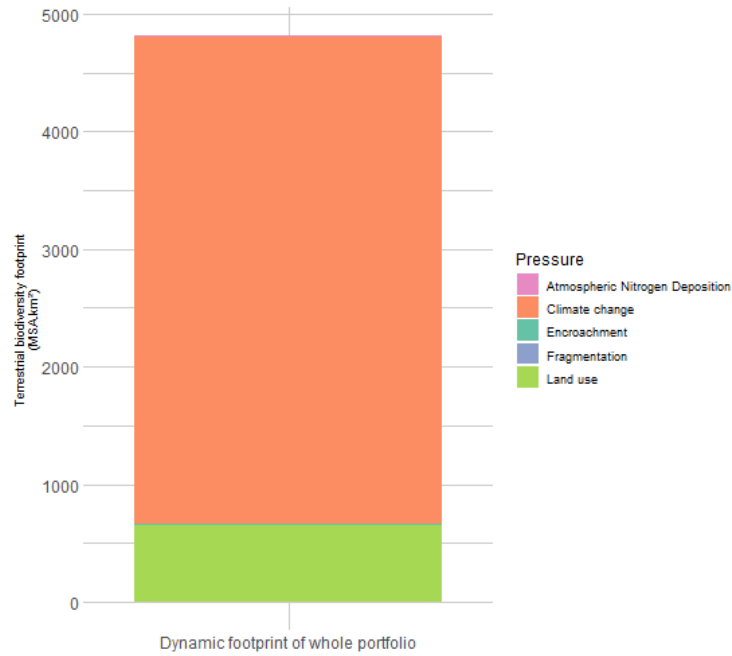
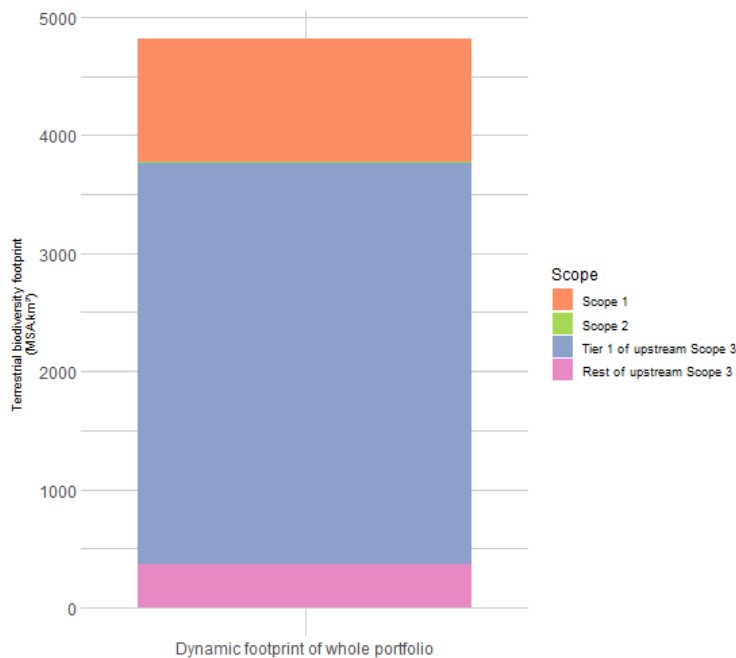


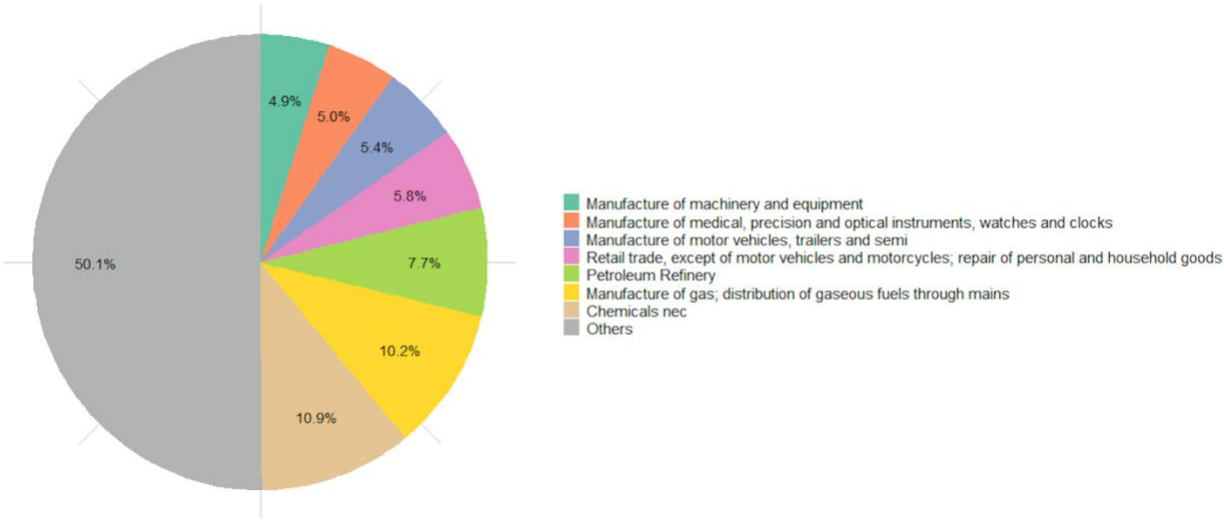
Figure 16.B – Dynamic biodiversity footprint of portfolio, by scope



The sectoral breakdown of the dynamic footprint (Figure 17) differs from that of the static one (Figure 14.A above). First, we observe that the footprint is slightly less concentrated: the top seven sectors contributing to the portfolio dynamic footprint account for 50% of it, compared with more than 60% for static impacts. In addition, the composition of the top seven sectors of

origin is different: while a large share of the static footprint originated from sectors related to food processing (using inputs from the agriculture sector, which has important impacts on terrestrial biodiversity through land-use-related pressures), the top sectors contributing to the dynamic footprint are mostly related to the manufacture and refining of fossil fuels, chemicals and trade. That is, once climate change pressure is accounted for, carbon-intensive sectors play a big role in explaining the dynamic footprint.

Figure 17 – Breakdown of dynamic biodiversity footprint of portfolio, by sector



### 6 Avenues for future research to further explore biodiversity-related financial risks (BRFR)

The previous two sections provided evidence of the materiality of the links between biodiversity, economics and the financial system. However, as discussed in Section 3.3, a full-fledged financial risk assessment would require having an idea not only of the exposure of the financial system, but also of the nature of the physical and/or transition shocks, including potential transmission channels across sectors, and of the adaptive capacity of economic and financial agents. How then can we embed the analyses of dependencies and impacts of the previous section within new approaches that account for the challenges discussed in Section 3.2 (complexity of ecosystems, incommensurability and incomparability of the processes aimed at valuing ecosystem services, and limited substitutability of natural capital)?

Without attempting to be exhaustive, we suggest that future research aimed at assessing BRFR while considering such methodological challenges could pursue three complementary avenues. First, by developing ad hoc scenarios that focus on specific shocks and specific contagion channels, with a focus on sectoral scenarios to avoid many limitations of existing economic models, as discussed in Section 3. For instance, one option could be to identify which assets could become stranded under specific scenarios. Second, in order to better account for the limited substitutability of natural capital and potential tail risks of biodiversity-related shocks,

methodologies based on cascades of stranded economic assets and financial contagions of environmental shocks could be used. Third, alternative approaches to risk management based on the concepts of double materiality and biodiversity alignment (which are increasingly supported by policymakers and financial regulators) could be developed. These three avenues are set out below, as a way of encouraging future work in these areas.

### 6.1 Towards ad hoc scenarios of biodiversity-related shocks

As discussed in Section 3, one difficulty in estimating BRFR has to do with the fact that no standard scenarios have been designed to assess the resilience of the financial system to specific biodiversity-related physical or transition shocks/hazards. This was also true for CRFR until recently, but it has started to change with the ongoing design of climate-related scenarios by the NGFS (2020) along with a consortium of climate-economy modelers (for a discussion see Pierfederici, 2020). The literature on CRFR also benefits from the earlier work on stranded assets, which had triggered the first financial estimates of transition risks (e.g. Carbon Tracker, 2013; McGlade & Ekins, 2015). In the absence of such scenarios, the assessment of biodiversity-related transition risks could aim to identify which assets would be most likely to become stranded in the case of a 'biodiversity transition'. This may be more difficult to do than for CRFR, given that there is not a specific activity (like the extraction fossil fuels with regard to climate change) that easily explains the vast majority of human-induced impacts on biodiversity.<sup>55</sup>

Nevertheless, some first steps toward better identifying biodiversity-related stranded assets can be envisioned. Some examples are set out below, without aiming to be exhaustive. As mentioned in Section 2, it is likely that COP 15 will lead to a commitment to protect 30% of terrestrial, freshwater and marine areas by 2030 (up from the current commitment of 17% of terrestrial and inland water areas, and 10 % of coastal and marine areas). If that was the case, some activities currently taking place within areas to be protected could become stranded. Van Toor et al. (2020) estimate that under a scenario in which 30% of terrestrial and freshwater areas become protected, the Dutch financial sector would have EUR 28 billion in exposures to companies that are active in protected areas. Calice et al. (2021) add some granularity to the scenario in the case of Brazil, by using governmental sources to determine which specific areas could become protected. It should nevertheless be kept in mind that such estimates do not account for the adaptive capacity of the firms exposed to such scenarios (put differently, it is implicitly assumed that firms that are exposed to these hazards will be unable to adapt).

More sector-specific scenarios could also be envisioned. For instance, to deal with the potential links between international trade and biodiversity loss discussed in Section 3, future scenario analysis could assess how stopping imported deforestation from low and middle-income economies (e.g. see WWF, 2021a) could expose financial institutions in high-income economies.

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<sup>55</sup> The agricultural sector contributes significantly to the biodiversity footprint, but the impacts are related to specific processes that need to be carefully assessed. In contrast, climate change refers in large part to specific inputs (e.g. fossil fuels) that are easier to identify through existing economic classifications.



New tools<sup>56</sup> could help by providing data on the entire supply chains of key commodities such as soy, palm oil and timber, which contribute to deforestation. Such tools could be used to get a more granular understanding of how financial institutions are exposed to deforestation-related financial risks. Sector-specific scenarios could also be tailored to each country. For instance, van Toor et al. (2020) assess how financial institutions could be exposed to policy developments requiring emissions of nitrogen to be reduced. Future scenario analysis could also focus on the sectors and specific agents (specific firms, but also households and governments through potential losses in revenue) that could be affected if biodiversity-related subsidies were to be modified. For instance, more than USD 1 trillion dollars are granted each year in the form of subsidies to activities that are harmful to the environment, such as fossil fuels, intensive agriculture or industrial fishing (Tobin-de la Puente & Mitchell, 2021).

While scenarios focusing on the primary sector may lead to relatively small financial exposures in high-income economies (given that agricultural activities tend to represent a relatively small share of GDP and of financial institutions' balance sheets in these countries), future scenarios could also focus on sectors that represent a higher share of financial institutions' balance sheets. For instance, in the case of France, the objective of zero net soil artificialization (set forth in France's *Plan Biodiversité* (Ministry for the Ecological Transition, 2018)) could have significant impacts on the real estate sector by limiting urban sprawl (France Stratégie, 2019). Assessing which specific areas and players could be affected, and how financial institutions are exposed to them, could therefore reveal new transition risks.

The examples above have focused on transition sources of risks, but ad hoc scenarios could also focus on physical sources of risks, among others by building on case studies (see WWF, 2021b, 2021c). It should nevertheless be noted that the outcomes of each scenario presented above provide only a limited and partial view of BRFR. Moreover, adding the risks of different scenarios would be useful but not sufficient, as it would not capture how these risks can reinforce each other and create emerging phenomena. Lastly, the question of how future scenarios could explicitly account for patterns such as the non-linearity and limited or non-substitutability of natural capital has not been discussed. To do so, it is necessary to assess future scenarios through specific approaches such as those discussed next.

## 6.2 Embedding biodiversity-related shocks in models of economic cascades and financial contagion

The methodologies and results explored in Sections 4 and 5 and the scenarios discussed in Section 6.1 cannot, on their own, address two of the main challenges discussed in Section 3: those of non-substitutability and non-linearity (including tail risks). As a result, the assessment of BRFR faces the risk of missing or underassessing the potential green swans that could result from

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<sup>56</sup> For instance, Trase ([www.trase.earth](http://www.trase.earth)) brings together publicly available data to map how the production of several commodities (e.g. soy, palm oil, timber and beef) depends on deforestation.

sudden physical or transition shocks. A case in point is the Covid-19 pandemic:<sup>57</sup> even if the scenario narrative had accounted for the emergence of the virus in one specific place in the world, this would not have been sufficient to envision all the cascading effects on both the supply and demand sides of the economy and on the financial system that the world economy has experienced since 2020. Previous studies acknowledge that current assessments of BRFR tend to be conservative and do not account for tail risks (e.g. van Toor et al., 2020).

In this context, two developments in the literature are particularly promising for assessing the potential transmission of biodiversity-related shocks throughout the economic and financial systems. First, specific approaches can reflect how biodiversity-related shocks can propagate throughout economic sectors, in a similar manner to the Covid-19 shock. Cahen-Fourot et al. (2021) build on input-output tables to show how environmental shocks (climate-related ones in their case) due to asset stranding can reduce production in one sector before cascading to other sectors that use the production of the first sector as input to their own production. For instance, a sudden fall in the extraction of fossil fuels could impact downstream activities, from oil refining to land transport and so on. These shocks could also be assessed from the demand side. For example, Godin & Hadji-Lazaro (2020) detail how a loss in exports in carbon intensive sectors, e.g. coal, also affects non-carbon intensive sectors, e.g. financial services or computer services, through the propagation of production loss through the entire production chain. Such approaches would be particularly useful to assess the transmission of risks if non-substitutable forms of natural capital become stranded.

Moreover, once the cascading effects of biodiversity-related shocks are better understood, one can go on to estimate the vulnerability of exposed firms. Godin & Hadji-Lazaro (2020) use two financial indicators (net debt over gross operating surplus, and net debt over total assets) to assess the financial consequences, at the sectoral level, of the export loss scenario. However, a limitation of these input-output based approaches to assess systemic impacts lies in the lack of connection between sectoral impacts and impacts at the firm level. Being able to characterize the distribution of income, debt or profits could help prevent this drawback and construct probabilities of impact at the firm level from aggregated impacts in the sector. Another limitation stems from the static nature of the input-output approach.

In addition to the cascading risks in the economic system, future assessments of BRFR could also account for their contagion throughout the financial system. Indeed, if biodiversity-related shocks lead to an increase in non-performing loans or a decrease in market valuations for some sectors or firms, it is possible that these shocks will also propagate across financial institutions. For instance, by integrating the 'real economy' impacts of environmental shocks into network valuations of financial assets, Roncoroni et al. (2021) show that relatively mild initial shocks can end up propagating throughout the financial system. The assessment of BRFR could gain much from assessing how biodiversity-related shocks could ultimately spread to the financial system through diverse channels studied in the literature (e.g. Idier & Piquard, 2017), such as

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<sup>57</sup> This does not assume that the Covid-19 pandemic has its origins in the destruction of biodiversity. As mentioned above, the latter is deemed likely but has not been confirmed at the time of writing.

bank insolvency, market liquidity and fire sales. Finally, financial fragility propagating in the financial sector is then likely to feed back into the industrial sector via credit constraints or higher lending rates, hence leading to further adjustments in terms of production, investment and employment, among other things.

By merging these ‘real economy’ cascades and financial contagion effects, future studies would likely be able to better capture the nature of BRFR (including the limited substitutability of natural capital and potential non-linear patterns) and gain insights into some of the channels through which they may impact financial stability.

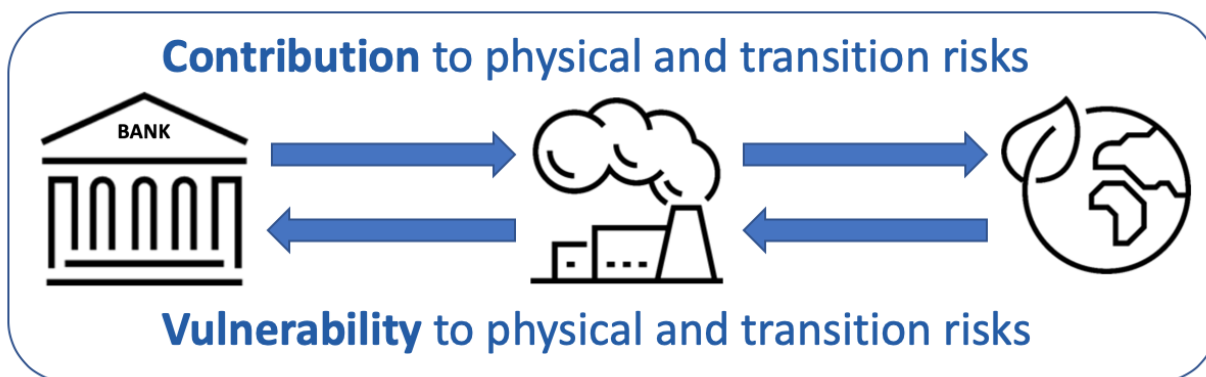
### 6.3 The case for biodiversity-alignment methodologies in the context a double materiality approach

#### 6.3.1 The theoretical case for a double materiality approach

The above reminds us that regardless of the approach one follows, much uncertainty will remain. Indeed, the nature of the shocks (Section 6.1) and their complex transmission channels to economic and financial agents (Section 6.2) are subject to multiple ecological and socioeconomic interactions that can be highly nonlinear. This makes a full evaluation of BRFR very difficult, if not impossible (OECD, 2021). Moreover, many BRFR cannot be mitigated individually, and therefore addressing biodiversity loss demands structural or "transformative changes" (IPBES, 2019) that central banks or financial institutions cannot deliver on their own. This observation leaves central banks in a dilemma, that of having to acknowledge a risk without being able to measure and manage it (Bolton et al., 2020a).

Against this backdrop, a promising avenue has been emerging with the concept of double materiality (see Figure 18), which indicates that it is not only environmental impacts that are material to firms and financial institutions, but also financial institutions’ and firms’ capital allocation decisions that are material to the natural environment (Täger, 2021). This concept therefore suggests that a comprehensive approach to environmental risks calls for jointly assessing these two related phenomena, i.e. the vulnerability of financial institutions to BRFR and their contribution to such risks. Indeed, the more the financial system degrades biodiversity, the more it can become exposed to physical risks (because of dependencies on degraded ecosystem services) and to transition risks (because it holds assets that could become stranded in the event of new policies). For instance, the CISL’s (2021) recent findings show that the global banking system contributes to deforestation through its loans, which means that it could be increasing its exposure to future physical shocks (if nothing is done) or transition shocks (if measures are implemented to halt deforestation). Kedward et al. (2021) argue that the ECB’s corporate bond purchase operations has considerable signaling power to financial markets, and should therefore minimize its impacts on issues such as imported deforestation.

Figure 18 – Double materiality



Source: adapted from Oman & Svartzman (2021)

From a theoretical perspective, the concept of double materiality can be considered to partially overcome the challenges discussed in Section 3.2 and in particular the need to ensure that the financial system does not contribute to crossing new tipping points. Utilizing a double materiality approach could therefore enable central banks and financial supervisors to be concerned about the impacts of the financial system not from an ‘activist’ perspective but rather because these impacts contribute to the build-up of future risks. Along these lines, the TNFD (2021, p. 3) indicates that non-financial and financial firms should report on “how nature may impact the organization, but also how the organization impacts nature”.

Disclosing through a double materiality approach (i.e. on both the vulnerability and contribution to BRFR) could increasingly become a regulatory requirement, to which central banks and financial supervisors should therefore pay attention. Indeed, the European Commission (2019) and the European Securities and Markets Authorities (ESMA, 2020) have already acknowledged the relevance of this concept in the case of CRFR.

### 6.3.2 Practical considerations toward the design of biodiversity-alignment methodologies

In France, the concept of double materiality is already enshrined (although not mentioned as such) in Article 29 of the French Energy and Climate Act and in the material implementing it (*décret d'application*<sup>58</sup>). The latter sets forth that financial institutions shall, in addition to disclosing their exposure to BRFR, provide evidence of how their strategy contributes to decreasing impacts on biodiversity, in line with international goals regarding biodiversity protection. In practice, this calls for the development of new methodologies to assess the biodiversity impacts of financial institutions (such as the BIA-GBS methodology used in this paper) with a dynamic perspective, in order to explore how the impacts of each firm could evolve in the near future and whether they are aligned with international goals. Such methodologies already

<sup>58</sup> See: <https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000043541738>. The *décret d'application* notably requires financial institutions to provide: “une analyse de la contribution à la réduction des principales pressions et impacts sur la biodiversité définis par la Plateforme intergouvernementale scientifique et politique sur la biodiversité et les services écosystémiques”.

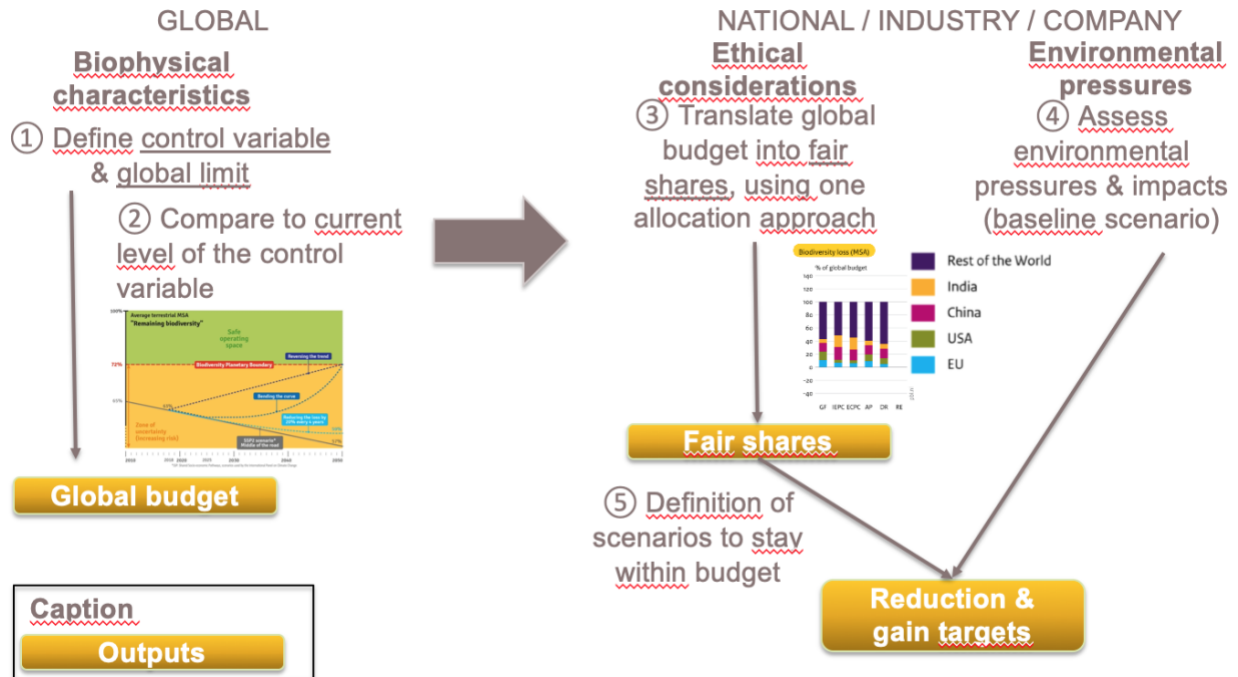
exist to assess the alignment of financial portfolios with climate goals (see Oustry et al., 2020; Raynaud et al., 2020)<sup>59</sup> but they remain in their infancy for biodiversity.

Different steps will be needed to develop the biodiversity-alignment methodologies (see Figures 19.A and 10.B). The first step consists in choosing one or more metrics that are compatible with the international biodiversity goals (the equivalent of the carbon budget available to meet the 1.5°C or 2°C target for climate change). In this regard, it is noteworthy that the BIA-GBS methodology can be used to translate international targets (e.g. no net loss in the area and integrity of ecosystems by 2030 and a gain of 20% by 2050, according to the early version of the CBD zero draft (CBD, 2020)) into MSA.km<sup>2</sup> at the sectoral level, and to compare them with current trajectories (see Steps 1 and 2 in Figure 19.A, and Figure 19.B for more details). Indeed, the planetary boundary for biodiversity loss is estimated to require maintaining 72% of terrestrial MSA (Lucas & Wilting, 2018), and the trajectory associated with the ecosystem target likely to be adopted during the CBD COP 15 could be translated into a global terrestrial MSA between 77% and 84% (see Figure 19.B). As a reference, only 65.8% MSA of terrestrial biodiversity was remaining in 2018 and about 0.27% MSA is being lost each year. Moreover, the current trend scenario is leading to a global MSA loss of 9.5% between 2010 and 2050 (Kok et al., 2018), meaning that only 58.5% MSA biodiversity would remain globally by 2050 (Kok et al. 2018, see Figure 19.B).

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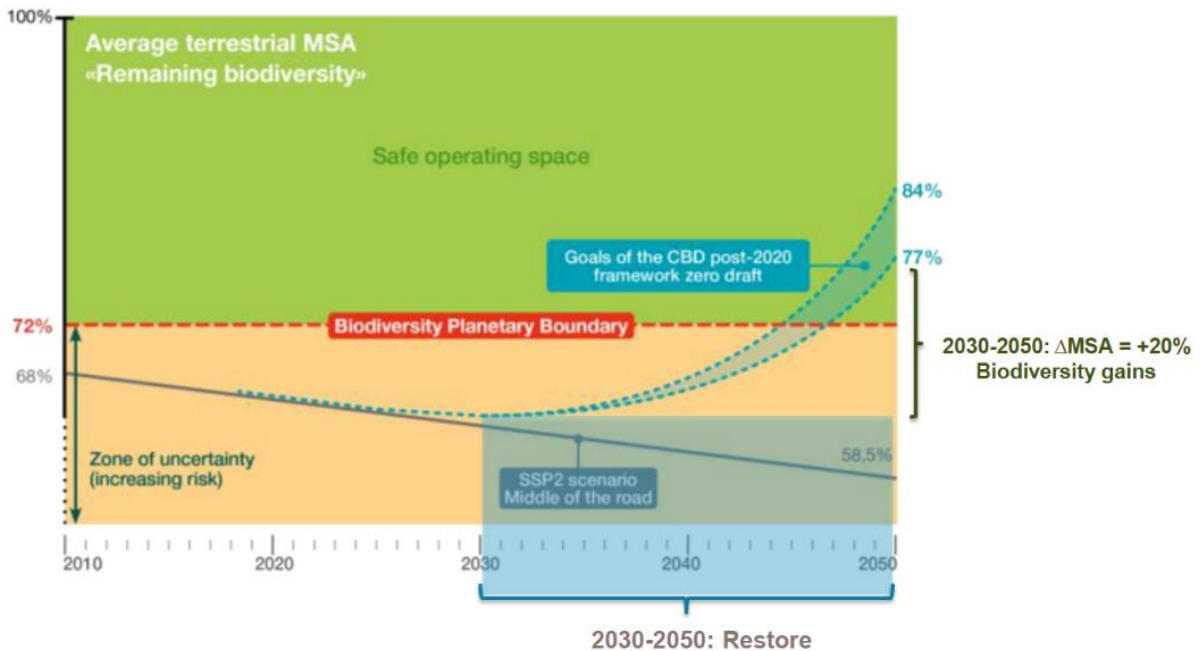
<sup>59</sup> These methodologies aim to estimate the alignment (or compatibility) of financial institutions' portfolios with a 1.5°C or 2°C target. These methodologies are usually based on three critical steps: the establishment of a global carbon budget required to meet a temperature target; an externally developed energy scenario that translates this carbon budget into specific regions and/or sectors' transition pathways and targets; and an ad hoc methodology to reconcile these regional/sectoral transition pathways with different entities' current emissions and medium-term strategies (based on multiple criteria such as the assessment of firms' R&D strategies or recent CO<sub>2</sub> emission performance).

Figure 19.A – The different steps needed to develop biodiversity-alignment methodologies



Source: CDC Biodiversité

Figure 19.B – Focus on Steps 1 and 2: Translating biodiversity international goals into MSA.km<sup>2</sup>



Source: CDC Biodiversité (2021)

The next step (see Step 3 in Figure 19.A) in developing these biodiversity-alignment methodologies would consist in translating, or allocating, the trajectories of biodiversity impact

reductions and gains (so as to achieve the goal of 72% or the range between 77% and 84% of MSA) into 'MSA budgets' for economic sectors. This could be done, for instance, by following allocation approaches such as that that will soon be developed by the Science Based Target Network (SBTN). These allocation approaches are likely to include a grandfathering approach<sup>60</sup> but other approaches based on other ethical considerations (such as capability, cost-effectiveness and other justice principles (Lucas & Wilting, 2018)) could also be developed. The final step (see Steps 4 and 5 in Figure 19.A) would consist in projecting the existing MSA.km<sup>2</sup> loss caused by a company into the future by creating metrics similar to those developed for climate alignment methodologies (e.g. by assessing each firm's investment strategy with regard to biodiversity). A 'MSA.km<sup>2</sup> delta' could then be calculated, much like the 'temperature delta' is estimated for climate alignment methodologies, by comparing current and projected impacts with the reduction required.

If central banks and financial supervisors were to follow such an approach, especially in light of Article 29 in France, it would nevertheless be necessary to be aware of the many limitations that apply to alignment methodologies (Raynaud et al., 2020), and all the more so in the case of biodiversity where the aggregation of non-fungible (loss of) units of ecosystem integrity or species is not the same as aggregating fungible CO<sub>2</sub> emissions. At the very least, it would be necessary to compare the results obtained through different methodologies and metrics before envisioning any specific action.<sup>61</sup>

Lastly, and while this is not absolutely necessary from a double materiality perspective, one could aim to reconcile these non-monetary metrics with monetary metrics, by attributing a value to the 'unit of misalignment'. One avenue to do is to attribute a restoration cost for each 'net gain' of MSA.m<sup>2</sup>. For instance, CDC Biodiversité's (2019) preliminary inquiry into this issue suggests that significant gains of MSA could be achieved with cost below EUR 5/MSA.m<sup>2</sup> through efforts such as energy efficiency (net gains) or the goal of protecting 30% of all terrestrial and marine areas (which entails relatively low costs, mainly related to the maintenance of areas). In contrast, land restoration would likely translate into significant costs for each 'recovered' MSA.m<sup>2</sup>. While this could provide some rough estimates of the costs for economic and financial agents, it remains difficult to allocate them to specific countries, let alone specific firms and households.

Another avenue would be to allocate a 'social value' to each unit of misalignment. For instance, a government could decide to tax the gap between the trajectory of a firm and the trajectory

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<sup>60</sup> The grandfathering approach means that the share of efforts required of each stakeholder equals their share of impacts at the beginning of the period. For instance, all companies would have to reduce their impact by 10% if the global goal is to reduce impact by 10%. The grandfathering approach can be highly problematic when applied to citizens or countries (e.g. because it would require poor and rich countries to reduce their impacts in the same proportion, regardless of their contribution to the current situation). The sectoral approach discussed here may lead to a less unfair approach to grandfathering. We nevertheless argue that other approaches should be explored, with a particular emphasis on allocations that reflect a concern for a socially just transition.

<sup>61</sup> For instance, and although it is not a biodiversity-alignment methodology, the ESGAP (Ekins et al., 2020) provides 22 indicators (such as biomass, freshwater, human health and terrestrial ecosystems) for which a measure between the distance (or misalignment) between current and desired trajectories can be measured. The indicator was tested on regions and countries such as the EU, Vietnam and Kenya.



needed to achieve global targets. Likewise, a central bank or financial supervisor could decide to assign a social value to this gap in the context of its own operations (including monetary operations) and functions (including the guarantee of financial stability). It is nevertheless clear that such a process could not take place without addressing the numerous limitations discussed above, and that any potential measure would need to be assessed in light of the ability of central banks and supervisors to comply with their primary mandate.

## 7 Conclusion

This paper has explored the topic of biodiversity-related financial risks (BRFR) in France, bringing three contributions to the emerging literature on this issue. First, we build on previous analytical frameworks aimed at characterizing these risks, with a more detailed discussion of three features: the complexity of ecosystems, including the non-linear patterns that could emerge when tipping points are crossed; the incomparable and incommensurable processes through which ecosystem services can be valued, meaning that there is no ‘fundamental’ value of biodiversity and no ‘true’ definition of the risks related to its loss; the limited substitutability of ‘natural capital’, which could lead to cascading risks that are not yet assessed in the literature. Together, these features indicate that while BRFR are real and may become systemic, exploring them requires developing new methodological approaches.

Second, we provide quantitative estimates of the dependencies of French financial institutions on ecosystem services and of the impacts of French financial institutions on biodiversity. We do so by building on van Toor et al. (2020), while including upstream dependencies. We find that 42% of the market value of securities held by French financial institutions are highly or very highly dependent on at least one ecosystem service (among the 21 considered in this study). We also find that the accumulated (or static) terrestrial biodiversity footprint of the securities held by French financial institutions in 2019 is comparable to the loss of at least 130,000km<sup>2</sup> of pristine nature, which corresponds to the complete artificialization of 24% of the area of metropolitan France, while the annual additional (or dynamic) impact on terrestrial biodiversity is equivalent to the loss of 4,800km<sup>2</sup> of ‘untouched’ nature, which corresponds to 48 times the area of Paris. Regarding the aquatic (freshwater) biodiversity footprint of French financial institutions: the accumulated (or static) footprint is comparable with the loss of 9,595km<sup>2</sup> of ‘pristine’ nature (1.7% of the area of metropolitan France), while the additional (dynamic) footprint each year can be compared to the loss of 92km<sup>2</sup> of ‘intact’ ecosystems (around the surface area of Paris). However, terrestrial and aquatic footprints cannot be compared without any context (as detailed in Annex 2.E).

These dependencies and impacts can be used to approximate or start assessing (respectively) physical and transition BRFR, and they suggest that the French financial system could be significantly exposed to both. However, more work will be needed to better understand how specifically biodiversity-related hazards could affect financial stability, while accounting for the

specific features of such risks (complexity, uncertain valuation processes, and limited substitutability) discussed in this paper.

Third, and as a result of the above, we discuss three avenues for future research to better identify BRFR. These relate to: (i) developing biodiversity-related scenario analysis tailored to financial risk assessment, with more granularity on the nature of the shocks we might face and their transmission channels to economic and financial agents; (ii) applying specific methodological approaches to capture the potential transmission of BRFR across many economic sectors and financial institutions, given the limited or non-substitutability of natural capital and/or the tail risks related to crossing tipping points; and (iii) working with ad hoc conceptual frameworks such as double materiality (already reflected in French regulations), and in particular developing new tools through which the alignment of financial institutions with biodiversity-related goals could be assessed.

Future work could also explore how the risk-based perspective of this paper could be complemented by other approaches that focus on the opportunities provided by an ecological transition. Indeed, the latter could create a number of opportunities (e.g. with respect to jobs (International Labour Organization, 2018; Saget et al., 2020)) and lead to structural economic changes that would transform every single economic sector, thereby rendering risk analysis less robust. It is therefore important to assess how central banks and financial supervisors should act in this context, and in particular how they should coordinate their potential actions with other players (Bolton et al., 2020a).

Overall, this paper contributes to further uncovering the linkages between biodiversity loss and financial instability, while emphasizing the numerous associated caveats and sources of uncertainty.

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## Annexes

- Annexes 1: related to the background content discussed in Sections 2 and 3
- Annexes 2: related to the Methodology (Section 4) and Results (Section 5)

## Annex 1.A – The European and French regulatory frameworks to address biodiversity loss

France's action in the field of biodiversity comes within the European Union's regulatory framework. Some of the EU initiatives include: Natura 2000 (the largest network of protected areas in the world, covering 18% of the EU's land surface and 6% of its sea surface); the directive on pollution caused by certain dangerous substances discharged into the aquatic environment (1976); the Urban Waste-Water Treatment Directive (1991); the Nitrates Directive (1991); the Water Framework Directive (2000); the Marine Strategy Framework Directive (2008); and the Regulation on the Prevention And Management Of The Introduction And Spread Of Invasive Alien Species (2014).

Until 2020, the EU relied on the European Biodiversity Strategy, which transposed the Aichi targets at the European level. In May 2020, the Commission published a new roadmap for 2030 (European Commission, 2020). This roadmap strengthens many objectives, notably by raising the target for protected land and sea areas to 30%. Other European regulatory and strategic developments are of particular importance for the topic of biodiversity. In particular, the European Farm to Fork Strategy (European Commission, 2020) sets an ambitious transformation plan for the food system, which could have impacts on several economic sectors. For instance, it aims to achieve a reduction in meat consumption and in synthetic inputs such as pesticides, fertilizers and antibiotics. Achieving such results, in turn, would involve potentially far-reaching transformations of the European Common Agricultural Policy, new industrial strategies for the food sector and even renegotiations of international trade agreements in order to avoid negative impacts on biodiversity (see Aubert, 2020), such as those caused by imported deforestation.

The French regulatory framework to protect ecosystems and their diversity is mainly driven by this EU framework. While older policies tended to focus on protecting specific areas (e.g. national parks, regional parks and natural reserves), the last two decades have seen the emergence of an active cross-sectoral and more holistic strategy, including:

- In 2004, the National Strategy for Biodiversity (SNB – *Stratégie Nationale pour la Biodiversité*), a text that aims to provide a general framework for the protection of biodiversity, was drafted to transpose France's commitments to the CBD to the national level. The SNB was revised in 2010 to take into account the Aichi objectives, and therefore targets an extension of protected areas, the limitation of urban sprawl, the reduction of pesticide use and the implementation of fiscal measures in favor of biodiversity. Nevertheless, the SNB does not have a binding dimension. A third SNB (2021-2030) is currently being developed under the responsibility of the Ministry for the Ecological Transition.
- In 2016, the *Loi pour la Reconquête de la Biodiversité* established the French Biodiversity Agency and enshrined in French law fundamental legal principles for biodiversity, such as the objective of “zero net loss”, the concept of ecological harm and the principle of interdependence with nature;
- In 2018, the *Plan Biodiversité* (Ministry for the Ecological Transition, 2018) provided a financial framework to support the goal of “net zero biodiversity loss”. It contributed to the funding of 90 concrete actions. Most of the actions are compensation actions

(e.g. conversion of an industrial wasteland) or subsidies (e.g. financial subsidies to organic farming). The *Plan Biodiversité* also included new objectives (e.g. zero plastic discharged into the sea by 2025) and a set of bans within various timelines. However, some of these bans have been postponed – most notably on glyphosate and on neonicotinoids – and a national experts council (Bougrain-Dubourg & Ferry, 2020) has pointed out that implementation of this plan is too patchy.

- Introduced by the French government in February 2021, the *Climat et Résilience* bill includes several measures related to biodiversity, including the strengthening of sanctions for offenses to nature and the inclusion of a guarantee for biodiversity preservation in the French Constitution, although the severity with which these measures should be practically implemented is still an open question.

However, as analyzed among others by Bureau et al. (2020) and Levrel (2020), the overall results of biodiversity conservation policies are disappointing both at European and national levels, as they have failed to stop biodiversity loss.

## Annex 1.B – A non-exhaustive discussion of “transformative changes” (IPBES, 2019)

Transformative changes consist of “a fundamental, system-wide reorganization across technological, economic and social factors, including paradigms, goals and values” (IPBES, 2019). Without aiming to be exhaustive, some examples of transformative changes addressed in the literature relate to the need to revisit:

- The belief in unlimited GDP growth: Dasgupta (2021) emphasizes the need to develop new measures of economic progress but also to explore the tensions that can arise between the goals of preserving biodiversity and increasing GDP. For instance, he argues that “we will not be able to extricate ourselves from the Earth System even if we try to invest continually for indefinite economic growth [...] The finiteness of Nature places bounds on the extent to which GDP can be imagined to grow. It also places bounds on the extent to which inclusive wealth can grow.” (Dasgupta, 2021, p. 47). There is an abundant and growing literature on the potential ecological limits to GDP growth (see e.g. Keyßer & Lenzen, 2021), but the latter has not yet been connected to studies of financial stability.
- Existing institutional arrangements with respect to property regimes: through hundreds of case studies conducted in different geographical areas and on several type of resources (mostly fisheries and wild animals, forests and savannahs, grazing lands, and water), Ostrom (2009) and her numerous colleagues from different scientific disciplines showed that there is a great diversity as to how common pool resources (CPRs) are managed, and that these extend way beyond traditional concepts of private and public goods. For instance, in contrast to standard economics’ suggestion that the commons are condemned to be depleted (given that agents would freeride on a resource lacking property rights), Ostrom’s work highlights other aspects of greater importance, such as the ability to regulate who can access the commons and under what conditions. That is, the focus is placed on the right to collectively ‘use’ a resource rather than the right to privately ‘own’ it (Dron et al., 2020). As a result, standard economics approaches grounded in pricing mechanisms to internalize externalities may become less applicable.
- Global trade: the IPBES (2020, p.4) argues that “the recent exponential rise in consumption and trade, driven by demand in developed countries and emerging economies, as well as by demographic pressure, has led to a series of emerging diseases that originate mainly in biodiverse developing countries, driven by global consumption patterns.” And Dasgupta (2021, p. 334) adds that we should “curb our enthusiasm for free trade in a distorted world”, especially as over-consumption from developed economies (about half of humanity’s impact on the biosphere can be attributed to 16% of the world’s population (Barrett et al., 2020), and more than half of biodiversity loss caused by consumption in developed economies occurs outside their territorial boundaries (Wilting et al., 2017)) that does not account for the environmental consequences in less developed economies can amount to a form of “transfer of wealth from the exporting to the importing country” (Dasgupta , 2021, p. 335).
- The role and ‘values’ of the financial system: while financial actors have a role to play in addressing biodiversity loss, they cannot provide public and common goods (such as biodiversity and a large part of ecosystem services) without broader government and regulatory policies (Dasgupta, 2021; Fétiveau et al., 2014). These findings play strongly

against the existing temptations to transform nature into an asset class, as the latter would likely lead to generating rents on scarce resources or ecosystems (i.e. it would value an ecosystem from an asset owner's perspective) without offering any guarantee that it would preserve the public good that biodiversity constitutes. Likewise, the concept of investing 'in' nature remains elusive when not approached through a broader institutional perspective, and can easily mask the fact that a different approach may be required to evaluate the nature of the links between biodiversity and finance. For instance, in the case of conservation, "investment can be passive, [it] can mean simply waiting" (Dasgupta, 2021, p. 40), implying among other things that financial returns are not always possible (Suttor-Sorel & Hercelin, 2020) unless one extracts rents from the management of an ecosystem. In other words, biodiversity protection cannot be solved simply by solving a theoretical investment gap: it also requires delving deeper into the nature of the relations between macrofinancial and ecological systems (which is beyond the scope of this paper, but nevertheless informs it). Moreover, it should be recalled that "while financial actors have a key role to play [...] through greater channeling of financial flows towards natural assets and their sustainable use – it should be stressed that their role is ultimately bound by broader government and regulatory policies to correct for institutional failures [...] Pricing and allocation of financial flows alone will not be sufficient to enable a sustainable engagement with Nature." (Dasgupta, 2021, p. 467).

- The role of risk analysis in the context of structural change: the overall effects of the just transition will be composed of interacting dynamics over the various networks mentioned throughout this paper, and will depend strongly on the shifts of behaviors observed in response to these dynamics. It is difficult to say whether the overall impacts will be negative or positive. There is nonetheless evidence that the ecological transition is a net creator of employment (International Labour Organization, 2018; Saget et al., 2020). Furthermore, the multiple and diversified effects that the transition imply require multi-criteria analysis in order to elucidate the trade-offs and policy choices that have to be made. Trying to synthesize the effects of a just transition in terms of value at risk or potential GDP per capita is likely to encounter many drawbacks related to monetization (Temel et al., 2018). Finally, it is important to note that the ecological transition will require undergoing what Carlotta Perez (2010) calls a techno-economic paradigm shift. The concept of techno-economic paradigm reveals the fundamental role played by the socio-institutional context. Institutions evolve in an adaptive way under the pressure of the structural change process taking place in the economic system. However, it takes a long time for social institutions to change. It is thus important to try to understand how the productive structure of the economy could evolve, taking into account the interactions between that structure and the socio-institutional context.

## Annex 1.C – The growing awareness of biodiversity-related financial risks (BRFR)

The recent and growing awareness of BRFR among central bankers and financial supervisors (e.g. INSPIRE & NGFS, 2021; van Toor et al., 2020) has been preceded by several initiatives. Some of them are outlined below.

**Policymakers** are increasingly aware of the need to work on the interactions at play between ecosystems and the financial system. The G7 conference held in France in 2019 underlined that biodiversity is the next frontier for financial regulation (PwC & WWF, 2020), and the 2021 G7 conference stated that “As we continue to address the ongoing pandemic, we acknowledge with grave concern that the unprecedented and interdependent crises of climate change and biodiversity loss pose an existential threat to nature, people, prosperity and security. We recognize that some of the key drivers of global biodiversity loss and climate change are the same as those that increase the risk of zoonoses, which can lead to pandemics”. Meanwhile, the World Economic Forum (2021) considers that biodiversity loss has become one of the main risks to the global economy along with climate change. In its report, *Biodiversity: Finance and the Economic and Business Case for Action*, the OECD (2019) establishes a typology of BRFR including physical and transition sources of risks and different channels through which they could affect the financial system.

Along the same lines, **civil society organizations** are also increasingly drawing attention to BRFR. Finance Watch (2019) indicates that “the risk of environmental collapse, resulting from natural capital depletion, is more and more described as a systemic risk”, and calls for central banks and financial supervisory authorities to assess and mitigate these risks within the remit of their mandates. WWF & PwC (2020, p. 35) reach similar conclusions and call for the NGFS to “analyze the impact of biodiversity-related financial risks on the microprudential and macroprudential risks in their financial sectors”.

**Private initiatives** related to BRFR have also emerged (e.g. Finance for Biodiversity, 2021). In particular, the TNFD (Task Force for Nature Related Financial Risk and Disclosure, at the intersection between the private, public and civil society spheres), which should become operational in the near future, seeks “to provide a framework for corporates and financial institutions to assess, manage and report on their dependencies and impacts on nature, aiding in the appraisal of nature-related risk and the redirection of global financial flows away from nature-negative outcomes and towards nature-positive outcomes”.<sup>62</sup> The French reinsurer SCOR recently examined how insurers and reinsurers can be affected by BRFR, noting that such risks are subject to uncertainty and non-linearity, and that they could become systemic (Chandellier & Malacain, 2021). Other private initiatives include the Natural Capital Alliance and Business for Positive Biodiversity (B4B+) launched by CDC Biodiversité, in which many financial institutions take part.

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<sup>62</sup> See: <https://tnfd.info/why-a-task-force-is-needed/>

**The academic community** is also emphasizing the importance of BRFR. For instance, the Dasgupta (2021) Review dedicates a full chapter to the financial risks posed by biodiversity loss. It argues that the decline in biodiversity could fuel “extreme risk and uncertainty” and cause a systemic financial crisis. Bassen et al. (2019) find that some nature-related patterns are already translating into financial risks, by affecting real estate prices and stock prices *inter alia*. Kedward et al. (2020) provide a thorough review of nature-related financial risks and find that given the complexity of ecosystems, such risks would be better understood through the concept of radical uncertainty. They further argue that in order to manage them, a precautionary approach is needed, which would enable central banks and financial supervisors to integrate such risks into all their operations without needing to measure them first.

## Annex 2.A – Alternative method for each of the steps described in the Methodology (Section 4)

**1 – Alternative method to link securities to their issuer.** Without access to this C4F referential, one can directly use the SHS dataset where the information on the Issuing company of each security is also available. However, the information on the issuer may be less precise than the one that is obtained with the C4F database. Indeed, the names of issuers in the SHS database may be that of a holding company rather than the name of the part of the company that really uses the investment for production. This may thereafter bias the dependency scores and biodiversity footprint obtained for the security (as the investment could eventually be linked to the financial sector rather than to the potentially more biodiversity intensive or dependent sector in which the company actually operates).

**2 – Alternative method to obtaining the sector and region of the company's turnover.** An alternative way if one doesn't have access to BIA-GBS is the following:

- **Turnover:** the global turnover of each issuer can be obtained with another data provider, such as BloombergRefinitiv.
- **Sector:** one can obtain the main sector (in NACE Rev 2 4-digit format) of each issuer using the ECB's Centralized security database (CSDB). However, this goes with two limitations: first, this will attribute only one sector to each issuer and hence the dependency scores and footprint obtained will be less accurate, and second, the NACE sector provided by the CSDB is often a financial sector (M.70.10 - Activities of head offices or K.64.20 - Activities of holding companies) instead of the sector corresponding to the "real" production sector of the company. In this case, one should modify the sectors by hand by getting an idea of the true activity of the company. Otherwise, this may bias the results as the dependency from and impact on biodiversity of the financial sector is - at least indirectly - quite low.
- **Region:** one can obtain an idea of the main region of the world where the company's turnover comes from by using the information on the country of the issuer that is available in the SHS database. In this case, each issuer will be attributed a unique region.

Factset database may also be used to gather both the amount of turnover of each company and its sectorial and regional decomposition. Then, it will be necessary to make hypotheses to cross the information and obtain a given amount of turnover for each pair of (sector, region).

**3 – Alternative method to convert the sector and region into EXIOBASE3 format.**

- **For dependency assessment:** To compute Scope 1 (direct operations) dependencies only, there is no need to convert the regions and sectors into an EXIOBASE format. In this case, the assessor can simply link the ENCORE processes to the nomenclature of the sectors she uses (for example, the NACE Rev 2 nomenclature in the case of DNB (van Toor et al., 2020)). However, if the assessor is interested in computing the upstream dependencies of sectors, she will have to use an input-output table such as EXIOBASE and to convert the sectorial information into the nomenclature of this IO table.
- **For biodiversity footprint assessment:** One still needs to convert sectors and regions into the EXIOBASE3 (sectors, regions) that are then used by the GBS tool. Concordance tables



of various taxonomies with EXIOBASE are available here: <https://ntnu.app.box.com/s/ziox4zmkg3cdsg549brr0qaecskgjsd> (link coming from the EXIOBASE website). In particular, if one had previously obtained the sector of the issuer into a NACE format, a NACE Rev 2 - EXIOBASE2 (similar to EXIOBASE 3 in terms of industries) concordance table is available (<https://ntnu.app.box.com/s/ziox4zmkg3cdsg549brr0qaecskgjsd/file/682195219009> )

Annex 2.B – Attributing to each issuer the average dependency score and the biodiversity footprint of its sector-region pair (Details on steps described in Section 4.2)

If the turnover is split into multiple sectors  $s$  and multiple regions  $r$ :

- The multiple scores of Scope 1 (respectively upstream) dependency to a given ecosystem service  $e$ ,  $DS_{s,r}^e$ , are aggregated to obtain a unique score of Scope 1 (respectively upstream) dependency to a given ecosystem service for the company  $c$ ,  $DS_c^e$ . BIA-GBS aggregates the scores with a weighted mean<sup>63</sup>, where the weights correspond to the share of the company’s turnover that comes from each sector-region pair (note that in the case of Scope 1, dependency scores only depend on the sector and do not vary with regions, so the sum on  $r$  can be removed in the following expression):

$$DS_c^e = \sum_s \sum_r DS_{s,r}^e \times \frac{turnover_{s,r}}{turnover_c} \quad (\text{where } turnover_c = \sum_s \sum_r turnover_{s,r})$$

- The multiple biodiversity footprint intensities of turnover  $BFI_{s,r}$  are multiplied by the amount of turnover coming from the corresponding sectors  $s$  and regions  $r$ . Then, the (absolute) biodiversity footprint coming from each pair of sector-region are summed to obtain the biodiversity footprint for the company  $c$ ,  $BF_c$ .

$$BF_c = \sum_s \sum_r BFI_{s,r} \times turnover_{s,r}$$

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<sup>63</sup> This implies that if a company  $c$  has half of its turnover in sector 1 that is very highly dependent on a given ecosystem service  $e$  ( $DS_1^e = 100\%$ ) and half in sector 2 that has no dependency to this ecosystem service ( $DS_2^e = 0\%$ ), then the dependency score of company  $c$  to ecosystem service  $e$  will be considered Medium ( $DS_c^e = 50\%$ ). One could rather decide to attribute the biggest dependency score to the company ( $DS_c^e = \max(DS_1^e, DS_2^e)$ ), however this would mean that a company with a low share of turnover in a very dependent sector and a large share in a sector that does not depend on  $e$  would be considered very dependent, which would probably overestimate its global dependency score to  $e$ .

## Annex 2.C – Computing upstream dependency of sectors

The dependency scores obtained with ENCORE ( $DS_s^e$ ) measure the *Scope 1 (direct operations) dependencies* of EXIOBASE sectors. Scores can be then gathered in a Scope 1 dependency matrix  $D$ , taking ecosystem services on its 21 rows and industries on its 163 columns. The EXIOBASE3 input-output table is then used to calculate indirect *upstream dependency scores* ( $U_s^e$ ). The upstream dependency score assigned to a given sector  $i$  (for a particular ecosystem service) corresponds to the mean of the dependency score of all sector  $i$ 's suppliers weighted by their importance in the supply-chain of sector  $i$  (i.e. the value of their production integrated into the value produced by sector  $i$ ). Concretely, this upstream dependency score of sector  $i$  is measured by multiplying the share of inputs from each supplier in the value chain that is required for a unitary production in sector  $i$ , by the Scope 1 dependency scores of the suppliers in the value chain. More precisely, the matrix of total requirements coefficients (Leontief inverse,  $L^{-1}$  computed with EXIOBASE) is used to build a matrix  $\overline{(L - I)}$  in which each coefficient of the  $(L - I)$  matrix is divided by the sum of the  $(L - I)$  coefficients in its column<sup>64</sup>, in order to obtain the 'importance' of each sector  $j$  in the value chain of sector  $i$ . This matrix is then used in the calculation to obtain the matrix  $U$  of "upstream dependency scores":

$$U = D \times \overline{(L - I)}$$

Although the dependency scores are not initially regionalized, the total indirect dependency of a sector is nevertheless influenced by the location of its suppliers. Indeed, the mix of sectors indirectly involved in a sector's supply chain changes depending on the location of the industry providing inputs to that sector, hence the composition and strength of the associated ecosystem service dependencies. Therefore, even though two firms working in the same sector but in two different regions will have the same Scope 1 dependency score for a given ecosystem service, their upstream dependency scores will differ due to the difference in their value chains.

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<sup>64</sup> Formally,  $\overline{(L - I)} = (L - I) \times \text{diag}((1(L - I))^{-1})$  where 1 is the row vector of 1s.

## Annex 2.D – Key features of the Global Biodiversity Score (GBS)

The GBS tool has three key interesting features. First, it provides an **aggregate metric** (in MSA.km<sup>2</sup>) to assess the level of ecosystem degradation attributed to the businesses or portfolio. Second, it distinguishes between **permanent and dynamic impacts**. Finally, it accounts for the impacts on biodiversity along the **full upstream value chain**.

**An aggregate metric: the MSA.km<sup>2</sup>.** The biodiversity footprint is expressed in this paper in MSA.km<sup>2</sup>. The Means Species Abundance (MSA) describes biodiversity changes with reference to the undisturbed state of ecosystems. It is defined as the average abundances of originally occurring species relative to their abundance in the undisturbed ecosystem<sup>65</sup>, understood here as equivalent to a pristine state, intact and undisturbed by human activity. Concretely, the MSA evaluates ecosystem integrity on a scale from 0%, for a land that is completely artificialized, to 100%, for the undisturbed ecosystem. This measure is then integrated on the surface under evaluation to obtain MSA.km<sup>2</sup>. **A loss of x MSA.km<sup>2</sup> is equivalent to the conversion of x km<sup>2</sup> of undisturbed ecosystem (with a MSA of 100%) into a totally artificialized area (MSA of 0%)<sup>66</sup>.** This measure bears various advantages: it brings information both on the integrity level of ecosystems and the surface on which this ecosystem quality is found, it is additive and relatively easy to understand.

**A distinction between static and dynamic impacts.** The dynamic footprint is the footprint caused by *changes (or flows)* in biodiversity (new biodiversity consumption, restoration or conservation) during the assessment period, while the static footprint includes all the “persistent effects” that remain over time (or stocks of impacts). These static impacts can range from the spatial footprint of existing facilities (excluding any consumption/expansion or restoration during the assessment period) to the past emissions and pollutions that still affect biodiversity today.

**Assessing the impacts along the full upstream value chain.** The GBS keeps the concept of Scopes developed by the GHG Protocol for climate footprinting and transposes it to biodiversity footprinting to delineate the impacts through the value chain. Scope 1 impacts represent the

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<sup>65</sup>

$$MSA = \frac{1}{N} \sum_{i=1}^N \min \left( \frac{A(i)}{A_0(i)}, 100\% \right)$$

Where

- MSA is the mean abundance of native species in the ecosystem
- N is the total number of species in an undisturbed ecosystem
- A(i) is the abundance of species i in the observed ecosystem
- A<sub>0</sub>(i) is the abundance of species i in an undisturbed ecosystem

<sup>66</sup> For the perimeter over which the impact is reported, it is assumed that out of 1km<sup>2</sup>, it is equivalent for biodiversity (i) to destroy completely (MSA of 0%) 25% of the square kilometre and leave the rest untouched (MSA of 100%) or (ii) to destroy only partly the ecosystem (MSA of 75%) on the whole surface of 1km<sup>2</sup>. This is a strong assumption and this calls for a reporting at the level of the “ecosystem asset” (rather than at the world level in our case), as recommended by the Biodiversity Protocol.

impacts of the company’s direct operations (e.g. for a travel agency: the impacts due to the artificialization of land for buildings or to the emission of GHG for heating the offices). Scope 2 brings together the impacts of GHG emissions due to energy purchases (e.g. for a travel agency that uses electricity for heating its offices: the impact of the GHG emissions of the coal power plant which produced the electricity, etc.). Finally, Scope 3 usually counts the impacts on biodiversity on the upstream and downstream value chain (e.g. for a travel agency: the biodiversity impact of the production of computers, company cars, etc. (upstream) and the impact on biodiversity of the consumers using the service: GHG emissions of transportation, land use of hotels, etc.). The way these impacts by scopes are obtained is detailed below.

Table – Pressures listed by the IPBES and covered by the GBS

<b>IPBES pressures</b>	<b>Pressures on terrestrial biodiversity covered by the GBS</b>	<b>Pressures on aquatic (freshwater) biodiversity covered by the GBS</b>
<b>Land and sea use change</b>	- Land use - Encroachment - Fragmentation of natural habitats	- Wetland conversion - Land use in catchment of rivers and wetlands
<b>Direct exploitation of organisms</b>	- Pressures related to agriculture, forestry and extraction	- Hydrological disturbance
<b>Climate change</b>	- Climate change	- Hydrological disturbance
<b>Pollution</b>	- Nitrogen atmospheric deposition - Terrestrial Ecotoxicity (under development)	- Freshwater eutrophication - Aquatic Ecotoxicity
<b>Invasive species</b>	/	/

## Annex 2.E – The freshwater biodiversity footprint of French financial institutions

This annex details the results we obtain regarding the impact of the security portfolio of French financial institutions on aquatic biodiversity. Note that this only accounts for freshwater biodiversity loss, as marine biodiversity is not covered yet by the GBS tool.

We find that the accumulated (or ‘static’) aquatic biodiversity footprint of the French financial system is comparable with the loss of 9,595km<sup>2</sup> of pristine nature (1.7% of the area of metropolitan France), while the additional (‘dynamic’) footprint each year can be compared to the loss of 92km<sup>2</sup> of intact ecosystems (around one time the area Paris).

Although these figures may appear rather low with regard to those obtained for the terrestrial biodiversity footprint (for which we found 130,000MSA.km<sup>2</sup> of static impact and 4,800km<sup>2</sup> of dynamic impact), the two types of impacts cannot be directly compared. Indeed, the area of terrestrial ecosystems on the globe represents 130 million km<sup>2</sup>, while aquatic freshwater ecosystems “only” cover 11 million km<sup>2</sup>. Hence, comparing the impacts in terms of terrestrial and freshwater biodiversity requires weighting them by the relative importance of terrestrial and freshwater ecosystems in terms of area over the earth surface. To do so, we use another metric, MSAppb, which aggregates terrestrial and aquatic impacts by expressing both as a fraction of their respective surface area and multiplying by 10<sup>9</sup> (parts per billion). We find the following impacts:

	Terrestrial biodiversity	Freshwater biodiversity
Static footprint	1000 MSAppb	872 MSAppb
Dynamic footprint	36 MSAppb	8 MSAppb

### Static footprint

The main drivers of the static footprint is the Land use in catchment of wetlands, followed by Wetland conversion and Hydrological disturbance due to direct water use. Overall, we see that many pressures are causing aquatic biodiversity loss. Just as for terrestrial biodiversity, the static footprint is mainly due to the upstream value chain rather than the Scope 1 of security issuers.

Figure 20.A – Static aquatic biodiversity footprint of portfolio, by pressure

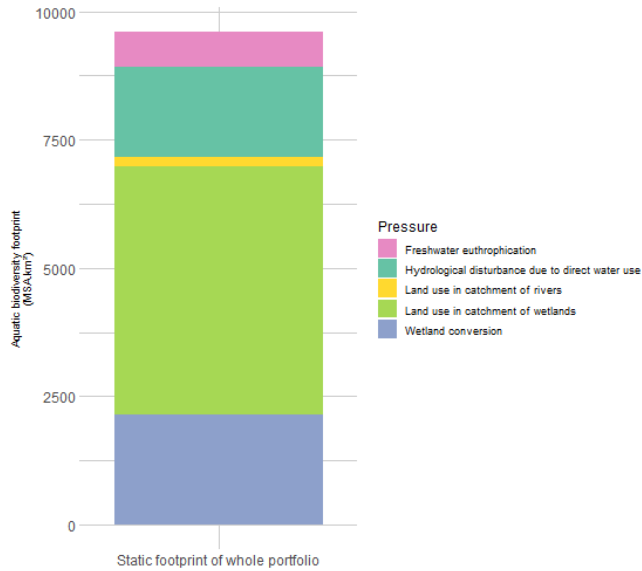
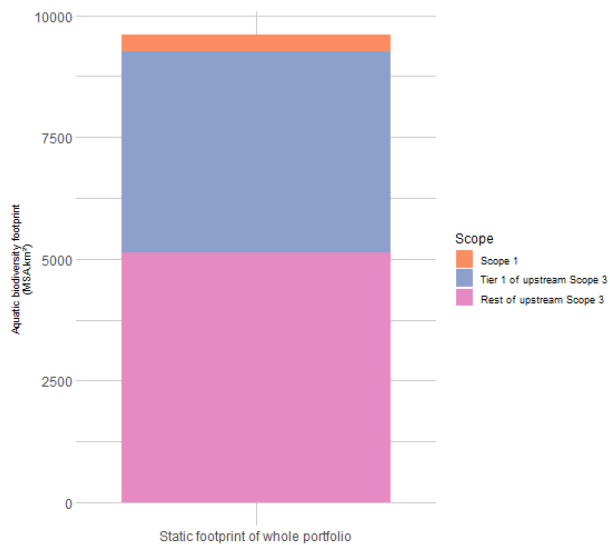
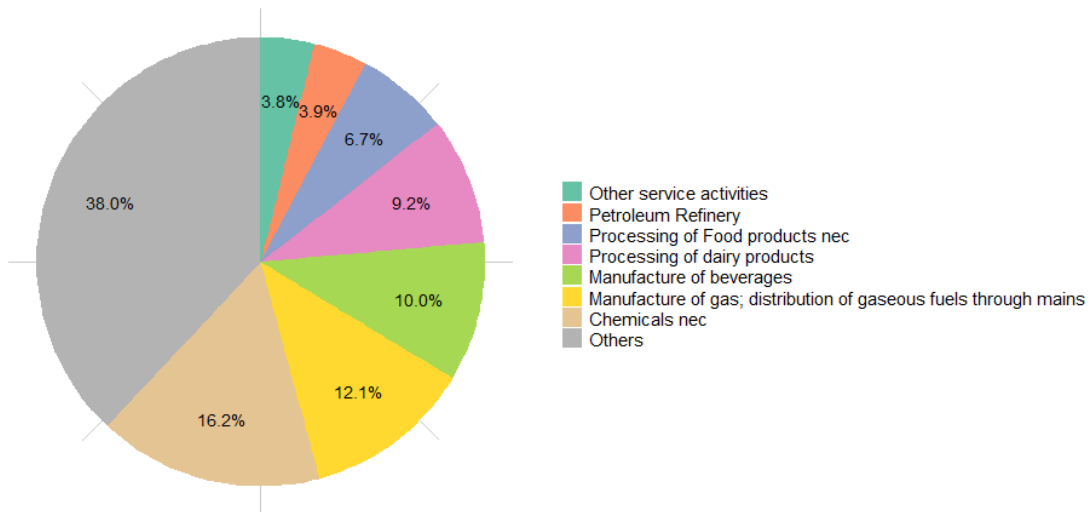


Figure 20.B – Static aquatic biodiversity footprint of portfolio, by scope



Looking at the sectorial decomposition of the static aquatic biodiversity footprint, we observe that it is even more concentrated in a few sectors than the terrestrial biodiversity footprint. However, the sectors from which the footprint originates remain rather similar (chemicals, gas and food processing), although we see the appearance of Petroleum refinery in the top 7 main sectors explaining the footprint.

Figure 20.C – Breakdown of static aquatic biodiversity footprint of portfolio, by sector



### Dynamic footprint

The dynamic footprint corresponds to the additional impact on biodiversity each year. It includes the pressure that climate change imposes on biodiversity, which is not the case for the static footprint (for methodological reasons). We find that the climate change becomes the most important pressure on aquatic biodiversity, followed by wetland conversion, while the contribution of Land use in catchment of wetland and Hydrological disturbance due to direct water use diminish in terms of importance as compared to the static footprint case. In terms of Scope, we find that the share of the dynamic footprint coming from Scope 1 is quite important. As for terrestrial biodiversity, this may be because the climate change pressure is accounted for, which allows to capture the scope 1 impact of the numerous companies in the portfolio that operate in fossil fuel-related sectors.

Figure 21.A – Dynamic aquatic biodiversity footprint of portfolio, by pressure



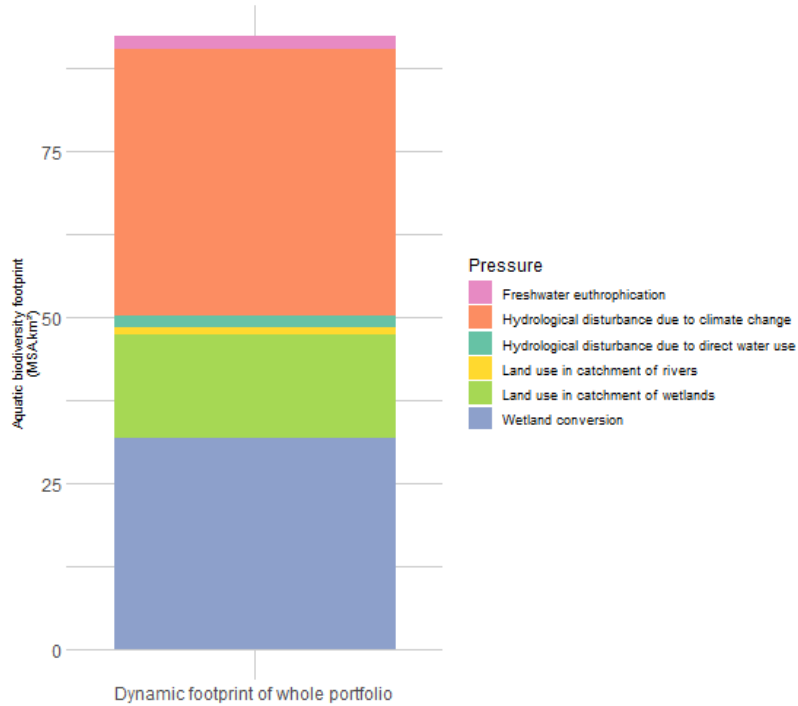
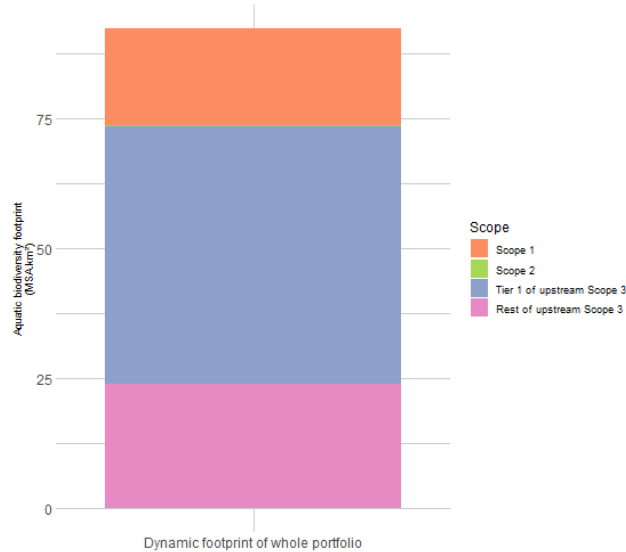
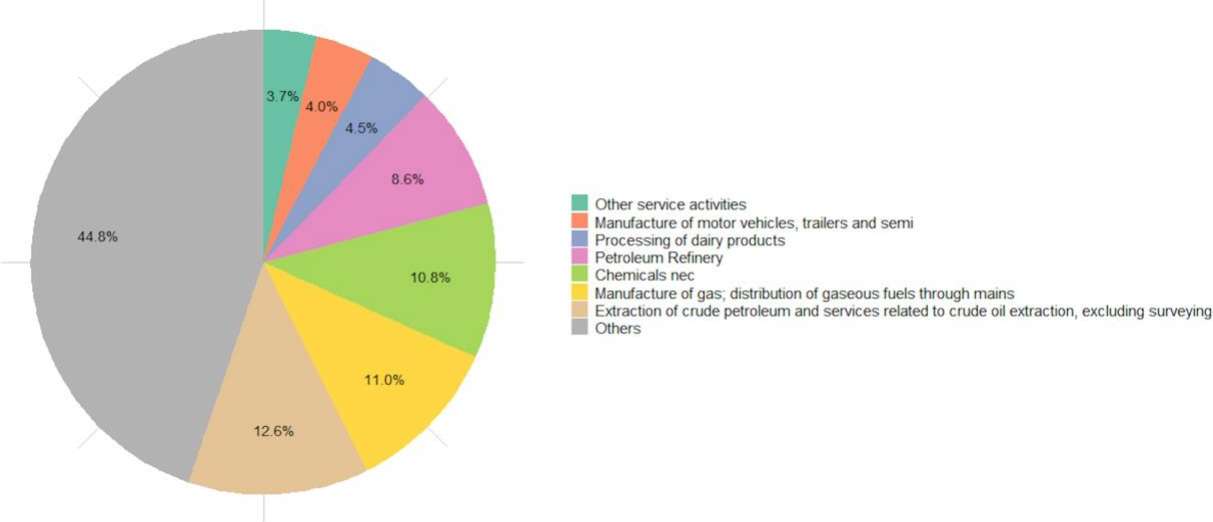


Figure 21.B – Dynamic aquatic biodiversity footprint of portfolio, by scope



Finally, we see that the sectors related to extraction and manufacture of fossil fuels (Extraction of crude petroleum, Manufacture of gas, Petroleum refinery) become very important to explain the dynamic aquatic footprint, as they explain more than 31 % of it.

Figure 21.C – Breakdown of dynamic aquatic biodiversity footprint of portfolio, by sector



Annex 2.F – Sectorial classification used in BIA-GBS

<b>Industry Type Code</b>	<b>Industry Type Name</b>
i01.a	Cultivation of paddy rice
i01.b	Cultivation of wheat
i01.c	Cultivation of cereal grains nec
i01.d	Cultivation of vegetables, fruit, nuts
i01.e	Cultivation of oil seeds
i01.f	Cultivation of sugar cane, sugar beet
i01.g	Cultivation of plant-based fibers
i01.h	Cultivation of crops nec
i01.i	Cattle farming
i01.j	Pigs farming
i01.k	Poultry farming
i01.l	Meat animals nec
i01.m	Animal products nec
i01.n	Raw milk
i01.o	Wool, silk-worm cocoons
i01.w.1	Manure treatment (conventional), storage and land application
i01.w.2	Manure treatment (biogas), storage and land application
i02	Forestry, logging and related service activities
i05	Fishing, operating of fish hatcheries and fish farms
i10	Mining of coal and lignite
i11.a	Extraction of crude petroleum and services related to crude oil extraction, excluding surveying
i11.b	Extraction of natural gas and services related to natural gas extraction, excluding surveying
i11.c	Extraction, liquefaction, and regasification of other petroleum and gaseous materials
i12	Mining of uranium and thorium ores
i13.1	Mining of iron ores
i13.20.11	Mining of copper ores and concentrates
i13.20.12	Mining of nickel ores and concentrates
i13.20.13	Mining of aluminium ores and concentrates
i13.20.14	Mining of precious metal ores and concentrates
i13.20.15	Mining of lead, zinc and tin ores and concentrates
i13.20.16	Mining of other non-ferrous metal ores and concentrates
i14.1	Quarrying of stone
i14.2	Quarrying of sand and clay
i14.3	Mining of chemical and fertilizer minerals, production of salt, other mining and quarrying n.e.c.

i15.a	Processing of meat cattle
i15.b	Processing of meat pigs
i15.c	Processing of meat poultry
i15.d	Production of meat products nec
i15.e	Processing vegetable oils and fats
i15.f	Processing of dairy products
i15.g	Processed rice
i15.h	Sugar refining
i15.i	Processing of Food products nec
i15.j	Manufacture of beverages
i15.k	Manufacture of fish products
i16	Manufacture of tobacco products
i17	Manufacture of textiles
i18	Manufacture of wearing apparel
i19	Tanning and dressing of leather
i20	Manufacture of wood and of products of wood and cork, except furniture
i20.w	Re-processing of secondary wood material into new wood material
i21.1	Pulp
i21.w.1	Re-processing of secondary paper into new pulp
i21.2	Paper
i22	Publishing, printing and reproduction of recorded media
i23.1	Manufacture of coke oven products
i23.2	Petroleum Refinery
i23.3	Processing of nuclear fuel
i24.1	Plastics, basic
i24.1.w	Re-processing of secondary plastic into new plastic
i24.2	N-fertiliser
i24.3	P- and other fertiliser
i24.4	Chemicals nec
i25	Manufacture of rubber and plastic products
i26.a	Manufacture of glass and glass products
i26.w.1	Re-processing of secondary glass into new glass
i26.b	Manufacture of ceramic goods
i26.c	Manufacture of bricks, tiles and construction products, in baked clay
i26.d	Manufacture of cement, lime and plaster
i26.d.w	Re-processing of ash into clinker
i26.e	Manufacture of other non-metallic mineral products n.e.c.
i27.a	Manufacture of basic iron and steel and of ferro-alloys and first products thereof
i27.a.w	Re-processing of secondary steel into new steel
i27.41	Precious metals production

i27.41.w	Re-processing of secondary precious metals into new precious metals
i27.42	Aluminium production
i27.42.w	Re-processing of secondary aluminium into new aluminium
i27.43	Lead, zinc and tin production
i27.43.w	Re-processing of secondary lead into new lead
i27.44	Copper production
i27.44.w	Re-processing of secondary copper into new copper
i27.45	Other non-ferrous metal production
i27.45.w	Re-processing of secondary other non-ferrous metals into new other non-ferrous metals
i27.5	Casting of metals
i28	Manufacture of fabricated metal products, except machinery and equipment
i29	Manufacture of machinery and equipment n.e.c.
i30	Manufacture of office machinery and computers
i31	Manufacture of electrical machinery and apparatus n.e.c.
i32	Manufacture of radio, television and communication equipment and apparatus
i33	Manufacture of medical, precision and optical instruments, watches and clocks
i34	Manufacture of motor vehicles, trailers and semi-trailers
i35	Manufacture of other transport equipment
i36	Manufacture of furniture
i37	Recycling of waste and scrap
i37.w.1	Recycling of bottles by direct reuse
i40.11.a	Production of electricity by coal
i40.11.b	Production of electricity by gas
i40.11.c	Production of electricity by nuclear
i40.11.d	Production of electricity by hydro
i40.11.e	Production of electricity by wind
i40.11.f	Production of electricity by petroleum and other oil derivatives
i40.11.g	Production of electricity by biomass and waste
i40.11.h	Production of electricity by solar photovoltaic
i40.11.i	Production of electricity by solar thermal
i40.11.j	Production of electricity by tide, wave, ocean
i40.11.k	Production of electricity by Geothermal
i40.11.l	Production of electricity nec
i40.12	Transmission of electricity
i40.13	Distribution and trade of electricity
i40.2	Manufacture of gas
i40.3	Steam and hot water supply
i41	Collection, purification and distribution of water

i45	Construction
i45.w	Re-processing of secondary construction material into aggregates
i50.a	Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessories
i50.b	Retail sale of automotive fuel
i51	Wholesale trade and commission trade, except of motor vehicles and motorcycles
i52	Retail trade, except of motor vehicles and motorcycles
i55	Hotels and restaurants
i60.1	Transport via railways
i60.2	Other land transport
i60.3	Transport via pipelines
i61.1	Sea and coastal water transport
i61.2	Inland water transport
i62	Air transport
i63	Supporting and auxiliary transport activities
i64	Post and telecommunications
i65	Financial intermediation, except insurance and pension funding
i66	Insurance and pension funding, except compulsory social security
i67	Activities auxiliary to financial intermediation
i70	Real estate activities
i71	Renting of machinery and equipment without operator and of personal and household goods
i72	Computer and related activities
i73	Research and development
i74	Other business activities
i75	Public administration and defence
i80	Education
i85	Health and social work
i90.1.a	Incineration of waste: Food
i90.1.b	Incineration of waste: Paper
i90.1.c	Incineration of waste: Plastic
i90.1.d	Incineration of waste: Metals and Inert materials
i90.1.e	Incineration of waste: Textiles
i90.1.f	Incineration of waste: Wood
i90.1.g	Incineration of waste: Oil/Hazardous waste
i90.3.a	Biogasification of food waste, incl. land application
i90.3.b	Biogasification of paper, incl. land application
i90.3.c	Biogasification of sewage sludge, incl. land application
i90.4.a	Composting of food waste, incl. land application
i90.4.b	Composting of paper and wood, incl. land application

i90.5.a	Waste water treatment, food
i90.5.b	Waste water treatment, other
i90.6.a	Landfill of waste: Food
i90.6.b	Landfill of waste: Paper
i90.6.c	Landfill of waste: Plastic
i90.6.d	Landfill of waste: Inert/metal/hazardous
i90.6.e	Landfill of waste: Textiles
i90.6.f	Landfill of waste: Wood
i91	Activities of membership organisation n.e.c.
i92	Recreational, cultural and sporting activities
i93	Other service activities
i95	Private households with employed persons
i99	Extra-territorial organizations and bodies