Biodiversity Risk *

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Abstract

We explore the effects of physical and regulatory risks related to biodiversity loss on asset values. We first develop a news-based measure of aggregate biodiversity risk and analyze how it varies over time. We also construct and publicly release several firm- and industry-level measures of exposure to biodiversity risk, based on (i) textual analyses of firms' 10-K statements, (ii) the holdings of biodiversity-related funds, (iii) firms' responses to a questionnaire fielded by the Carbon Disclosure Project, and (iv) a large survey of finance professionals, regulators, and academics. Exposures to biodiversity risk vary substantially across industries in a way that is economically sensible and distinct from exposures to climate risk. We find evidence that biodiversity risks already affect equity prices: returns of portfolios that are sorted on our measures of biodiversity risk exposure covary with innovations in the aggregate biodiversity risk index. However, our survey indicates that market participants do not perceive the current pricing of biodiversity risks in equity markets to be adequate.

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Over the past decades, policymakers, investors, and researchers have increasingly sought to understand and manage the complex relationships between economic activity and the health of our planet. For example, a series of treaties have codified commitments to slow global warming, and there have been numerous efforts from the business and finance communities to address the various risks from climate change. On the academic side, the field of climate finance has rapidly developed into an active area of research (see Giglio, Maggiori, Rao, Stroebel & Weber 2021, Stroebel & Wurgler 2021, Hong et al. 2020, for recent reviews). Yet climate change is only one facet of how the economy interacts with the natural world. In this paper, we examine another important and distinct dimension: the economic risks associated with *biodiversity loss.*

While biodiversity—commonly understood as the diversity of genes, species, and ecosystems—has long underpinned human survival and well-being, recent decades have seen sharp declines driven by human activity. The 2019 *Global Assessment* of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES 2019), for instance, documented that current species extinction rates are 10 to 100 times higher than the historical average of the past 10 million years.

Such biodiversity loss can have large negative consequences for the economy. A key reason is that biodiversity plays a fundamental role in the provision of *ecosystem services*, an important (though often ignored) factor of production alongside other factors like capital and labor (see, e.g., Daily et al. 1997, 2000, Heal 2000, Dasgupta et al. 2013, Giglio et al. 2024).[1] These ecosystem services include provisioning services such as food, fuel, and timber, as well as regulating services such as pollination, the provision of clean air and water, and pest control. The effect on aggregate economic output from a loss of such ecosystem services is generally difficult to compensate for by increasing capital or labor (Dietz & Neumayer 2007, Ekins et al. 2003). As a result, early estimates of the annual economic value provided by ecosystem services are in the tens of trillions of dollars (Costanza et al. 1997).

The negative effects of biodiversity loss on economic activity are likely heterogeneous across sectors and firms (Giglio et al. 2026). For example, some industries may be more exposed to the *physical* biodiversity risks due to their dependence on ecosystem services in the production process. Similarly, firms located near ecosystems at risk of collapse are more

[1] While it is true that in some instances—such as those involving invasive species—more diverse ecosystems may be less stable, a large literature in ecology has documented positive "biodiversity-stability" and "biodiversity-productivity" relationships that highlight that declines in biodiversity generally weaken an ecosystem's ability to provide ecosystem services (see reviews of this literature in Hooper et al. 2005, Giglio et al. 2024). This literature also highlights that not all species loss is equally damaging to the provision of ecosystem services: losing a species that is unique in its ability to perform its role in its ecosystem—sometimes called a "keystone species"—is more damaging than losing a different species that competes with other species to perform a given function.

exposed to the physical risks from further biodiversity declines.[2] In addition to the physical risks from biodiversity loss, *transition* risks from regulatory responses to biodiversity loss—such as those resulting from policy commitments made at the recent COP15 conference in Montreal—can also have substantial effects on economic activity and asset values, especially for industries that directly interact with and impact the natural environment.

The goal of this paper is to quantify how biodiversity risks vary in the cross-section of firms and industries, and to study whether asset values have begun to reflect these risks. To motivate our analysis, we first conduct a survey of the perceptions of biodiversity risks among 668 finance academics, professionals, public sector regulators, and policy economists from around the world. The survey shows broad and substantial concerns about the economic effects from biodiversity loss over relatively near-term horizons. Around 70% of respondents perceive physical and transition biodiversity risks to have at least moderate financial materiality for firms in the United States, with private sector respondents reporting the highest perceived financial materiality of these risks.

We next move to quantify the aggregate amount of biodiversity risk over time. A key issue with measuring risks such as those related to biodiversity loss is that they often unfold slowly over long horizons, making it hard to quantify risk and risk exposures using standard statistical tools. To overcome these challenges, we follow the approach developed in Engle et al. (2020) and build a biodiversity risk index using *news* about such risks extracted from newspaper coverage of topics associated with biodiversity loss.

Specifically, we construct a biodiversity news index by analyzing articles in the New York Times (NYT). We first develop a biodiversity dictionary containing a list of relevant terms such as "ecosystem" and "deforestation" that is used to identify articles in the NYT that cover biodiversity risks. We classify the sentiment of these articles using the Bidirectional Encoder Representations from Transformers, or BERT, a standard model from the natural language processing literature. The article-level sentiment is aggregated to compute a daily "NYT-Biodiversity News Index." We validate the index by showing that it spikes around important events regarding biodiversity risk (e.g., during ecological disasters or around new regulations to limit biodiversity loss). This high-frequency measure allows us to quantify the immediate impacts of changes in expectations about—or increased attention to—damages and regulations related to biodiversity loss, even if they might only materialize in the future.

To assess whether this aggregate biodiversity risk is reflected in asset prices, we start from the observation that the impacts of biodiversity risk realizations are heterogeneous across

[2]There are also non-pecuniary benefits associated to biodiversity, for example if some individuals put an intrinsic value on the existence of species. In this paper, we focus on the part of the value that comes from the contribution to economic production.

firms and industries. For example, diverse ecosystems are key to the production of food and nature-based materials such as timber (Duarte et al. 2009, Liang et al. 2016, Paul et al. 2020, Porto et al. 2020, Steffan-Dewenter et al. 2007), making those industries particularly exposed to physical biodiversity risks. In addition, many medicines, including antibiotics and cancer drugs, are derived from natural compounds found in plants, animals, and microorganisms, so the pharmaceutical industry is also exposed to this risk. Similarly, utility firms with large footprints in environmentally sensitive areas—including firms operating wind and solar farms—may be disproportionately affected by biodiversity transition risks.

However, while it is intuitive to expect biodiversity risk exposures to be heterogeneous across firms, the absence of standardized disclosure frameworks for physical and transition biodiversity risks makes it hard to quantify these exposures. We thus propose and compare several new ways to measure firms' biodiversity risk exposures; we publicly release these measures of exposure to biodiversity risk at `www.biodiversityrisk.org`.

Our first set of measures of biodiversity risk exposures, available at the firm level, is based on textual analysis of firms' 10-K statements to identify discussions of biodiversity-related risks. The second measure is created at the industry level from our survey of academics and professionals. The survey asked respondents to select the industries most negatively affected by biodiversity loss, distinguishing explicitly between physical and transition risks. Our third measure of biodiversity risk exposures is based on the holdings of five biodiversity-related funds. It is calculated by comparing the weight of an industry in the market portfolio to its weight in the biodiversity funds' portfolios, based on the assumption that industries that are underweighted relative to the market are negatively exposed to biodiversity risks. The last measure is derived from firms' responses to the CDP Climate Change Questionnaire, where firms disclose whether their activities impact biodiversity-sensitive areas. All these measures are meaningfully correlated in the cross-section: industries ranked high on biodiversity risk exposure on one measure generally also rank high on the other measures. The sectors with the highest average biodiversity risk exposures include Energy, Utilities, Real Estate, Food, and Pharmaceuticals, while firms in the Communication Services, Software, and Technology sectors have minimal direct exposures to biodiversity risks.

We then use our measures of news about aggregate biodiversity risk as well as our firm- and industry-level risk exposures to explore the extent to which biodiversity risks are currently incorporated into equity prices. To do so, we form equity portfolios of industries sorted by their biodiversity risk exposures. The portfolios hold long positions in industries with *low* biodiversity risk exposures and short positions in industries with *high* biodiversity risk exposures. If biodiversity risk is priced, the return of these biodiversity-risk-sorted portfolios should covary with the aggregate biodiversity news index, effectively behaving like a hedge

portfolio for biodiversity risk. We find that the correlations between the returns of our biodiversity hedge portfolios and AR(1) innovations in the biodiversity risk index are positive, with magnitudes as large as 0.2. These correlations are comparable to those obtained by climate hedge portfolios when evaluated against aggregate climate news (see Engle et al. 2020, Alekseev et al. 2024), and, more generally, to the hedging performance of portfolios built to hedge other macro risks such as consumption or GDP (see Giglio & Xiu 2021).

To explore if our measures of biodiversity risk exposure are simply recasting information from other firm characteristics, we compare the hedge performance of our measures with that of hedge portfolios constructed using other firm characteristics—specifically, the 212 characteristics in the "factor zoo" of Chen & Zimmermann (2022). We find that our biodiversity hedge portfolios perform significantly better than this universe of characteristics in hedging aggregate biodiversity risk. Overall, the evidence suggests that biodiversity risk has been at least partly priced in the cross-section of U.S. equities over the last decade.

We conclude by reviewing evidence from our survey on market participants' perceptions of whether biodiversity risks are *adequately* priced in financial markets. About half of the respondents believe that these risks are not sufficiently priced across stock, commodity, sovereign debt, and real estate markets, while 14% - 19% of respondents believe that they are correctly priced. Only a handful of respondents believe that biodiversity risks are overpriced in these asset markets (while about 35% of respondents had no opinion).

Throughout the paper, we explore the relationship between biodiversity risks and climate risks. The two risks are conceptually distinct, as biodiversity risk focuses on the threats to the variety of life on Earth and its consequences, while climate risk relates to the potential negative consequences of a change in the climate. As discussed in Giglio et al. (2024), the effects on aggregate output of these two types of risk realizations can be quite different, though they are obviously related. Despite this conceptual distinction, the two risks are interconnected through a "twin-crises multiplier" whereby climate change can exacerbate biodiversity loss, and biodiversity loss can drive climate change, for example through the destruction of carbon sinks (Giglio, Kuchler, Stroebel & Wang 2025). Given the recent academic and policy interest in climate change and its economic implications, it is important to distinguish the two types of risk not only qualitatively, but also quantitatively. We do so in several ways. First, we show that the aggregate biodiversity news index behaves differently from analogously constructed climate news index; second, we document that climate risk exposures and biodiversity risk exposures are only weakly related in the cross-section of industries; and finally, we show that portfolios built for hedging biodiversity risk do not perform well at hedging climate risk.

Related Literature Our work contributes to a growing literature that studies the interaction between financial markets, asset prices, and the health of our planet. Much recent research has studied the physical and transition risks relating to climate change (e.g., Alekseev et al. 2024, Engle et al. 2020, Giglio, Maggiori, Stroebel, Tan, Utkus & Xu 2025, Pástor et al. 2021, Sautner et al. 2023*b*, Bolton & Kacperczyk 2021*b*, 2020, 2023, 2021*a*, Ilhan et al. 2023, Grippa et al. 2019, Bolton & Kacperczyk 2022, Pástor et al. 2022, Choi et al. 2020, Giglio, Maggiori, Rao, Stroebel & Weber 2021, Bernstein et al. 2019, Baldauf et al. 2020, de Boyrie & Pavlova 2020, van Benthem et al. 2022, Acharya et al. 2023, 2025).

Much less work has been done to understand the effect of biodiversity risks on the economy and on asset prices. The key challenge is measuring its dynamics and firms' evolving exposures. To our knowledge, this paper is among the first to quantify aggregate biodiversity risk and firms' and industries' exposures. By addressing this research gap, we respond to the call for more research in Karolyi & Tobin-de la Puente (2022), and provide publicly available data sources to spur follow-up work on biodiversity risks at `www.biodiversityrisk.org`. In the last two years, several other time series measures of biodiversity risk have emerged. Incident-based measures, such as Xiong (2023), track the frequency of reported biodiversity incidents occurring within that country using RepRisk data, while news-based indices, such as Ma et al. (2024), capture sentiment in media coverage. These efforts provide complementary measures to our NYT-Biodiversity News Index. Estimates of cross-sectional exposure to biodiversity risk have also improved over time. Garel et al. (2024) and Coqueret et al. (2025) use the Corporate Biodiversity Footprint (CBF) from Iceberg Data Lab to assess firms' biodiversity impact, and thus their transition risk exposures. Garel et al. (2025) construct firm-level nature dependence measures using the ENCORE database. Other papers rely on ESG subindicators related to nature and biodiversity (Xin et al. 2023, Xiong 2023, Naffa & Czupy 2024, Hoepner et al. 2023). Becker et al. (2025) use MSCI Geographic Segment Exposure to Fragile Ecosystems, which assesses firms' operational presence in biodiversity-sensitive areas. Our measures are built from financial and disclosure data, and they are publicly available, replicable, and link directly to financial outcomes. Each, however, has limitations: 10-K measures depend on disclosure quality, surveys are updated infrequently, holdings data cover only limited periods, and CDP relies on voluntary reporting. Cross-geography measures of physical and transition risk exposure have also been explored (e.g., Bouyé et al. 2024, Huang et al. 2024). For example, Giglio et al. (2024) construct ecologically-founded country-level measures of ecosystem fragility, while Chen et al. (2023) build a dataset mapping the geographic locations of all National Nature Reserves in China.

Other researchers that examine how biodiversity risk is priced in equity markets include Garel et al. (2024), who find a biodiversity premium emerging following the Kunming Dec-

laration (see Xiong 2023, Kalhoro & Kyaw 2024, for related results). Further evidence is provided by Coqueret et al. (2025), who highlight a biodiversity risk premium in expected returns in U.S. sectors most exposed to biodiversity risks; consistent with the finding by Naffa & Czupy (2024) that biodiversity-screened portfolios yielded lower risk-adjusted returns compared to randomly selected portfolios in the U.S. from 2013 to 2023.[3]

1 Biodiversity Risks: Perception and Measurement

The economic and financial risks associated with biodiversity loss can be broadly divided into physical risks from the actual loss of biodiversity and transition risks from responses by regulators and consumers to reduce biodiversity loss (see OECD 2019, IFC 2019).

Physical risks encompass the financial and economic effects of the loss of biodiversity and the associated ecosystem services. For example, firms relying on specific natural resources, such as timber, may face scarcity or quality issues due to deforestation or habitat loss. This can lead to increased raw material costs and deteriorating supply chains. Similarly, biodiversity loss can negatively affect the R&D process in the pharma and biotech sectors. In addition to such direct effects, biodiversity loss can raise the likelihood of the emergence of various diseases and increase vulnerability to damages from climate change, for instance by reducing carbon sequestration capacity (Giglio, Kuchler, Stroebel & Wang 2025).

Besides the physical risks associated with biodiversity loss, firms may also be affected by risks from an increased focus of regulators and consumers on the preservation of biodiversity. For example, policies aimed at protecting biodiversity, such as land-use regulations and sustainable forestry requirements, may result in changes to asset values across a range of industries. Biodiversity transition risks also come from changing consumer preferences, such as shifts away from palm oil by consumers concerned about its effect on deforestation. In addition, legal and reputational biodiversity risks affect firms by increasing the cost of causing ecological disasters such as oil spills.

[3]Several studies explore the pricing of biodiversity risks in fixed income markets. Giglio et al. (2024) find that news about biodiversity loss increases credit default swap spreads more for countries with more depleted ecosystems. Similarly, Agarwala et al. (2022) show that downgrades of sovereign bonds are associated with growing nature-based risks. Examining infrastructure firms, Hoepner et al. (2023) show that firms with better biodiversity risk management enjoy more favorable financing conditions, reflected in lower CDS slopes. Cherief et al. (2022) highlight that corporate bond spreads for firms in biodiversity-intensive sectors widen following acute biodiversity events in Australia and Brazil. In municipal bonds, Rizzi (2022) find that losses in wetland areas are associated with increased yields and borrowing costs due to heightened downside risk and extreme weather uncertainty. Finally, Chen et al. (2023) find that the "Green Shield Action," a regulatory initiative to enforce biodiversity preservation in China, significantly increased bond yields for municipalities with national nature reserves. In the real estate market, Rizzi (2022) finds that home prices decrease when upstream wetlands are lost and increase when wetlands are gained, highlighting the impact of biodiversity loss and restoration on property values.

In this section, we aim to better understand the importance and evolution of biodiversity risks from an aggregate perspective. We first discuss findings from a survey of academics, financial professionals, and regulators about the relative importance of various biodiversity risks over different time horizons. We then describe a new measure of aggregate biodiversity risk over time, and highlight that the time-series movement of biodiversity risk is distinct from that of climate risk, which has been studied extensively in the academic literature.

1.1 Perceptions of the Importance of Biodiversity Risks

To measure perceptions of the importance of biodiversity risks, we surveyed finance researchers, professionals, and public sector employees in Q1 2023. To reach academics, we collected email addresses of about 4,500 faculty at the top 100 finance departments.[4] To reach practitioners, we contacted about 7,000 NYU Stern and Yale SOM graduates working in finance. To reach those involved in policy, we invited about 3,000 researchers or policymakers working in the finance-related groups of about 35 relevant public sector institutions to participate in our survey (see Appendix A.4 for the full list of these institutions)[5].

In total, we received 668 complete responses for an overall response rate of about 4.5%.[6] 48% of responses were from academic researchers, 34% from financial professionals, and 18% from financial regulators or public-sector employees. Our respondents' locations tilt toward North America (62%) and Europe (23%), with respondents from Asia and the Rest of the World making up 9% and 5% respectively. Appendix Table A.1 contains summary statistics and cross-tabulations of the demographic information reported by the survey respondents.

Appendix A.1 shows the flow of the survey. The first question asked respondents about how worried they were about ecosystem and species diversity loss. About 70% of respondents expressed substantial personal concern about each type of biodiversity loss.

To assess perceptions of the financial and economic implications of biodiversity risks, we asked survey participants to rate the financial materiality of physical and transition risks for U.S. firms and to indicate the expected time horizon of these risks. Table 1 presents the responses for different groups of respondents. Table 1 reports responses across different groups. Overall, both types of biodiversity risks are widely perceived as material—especially by private-sector respondents and those located in Africa, South America, and Australia.

[4] We used the ranking maintained at ASU based on the total number of articles published in the Journal of Finance, Journal of Financial Economics, and Review of Financial Studies from 2010 through 2023.

[5] While our survey respondents include a broad range of market participants, a recent survey by Gjerde et al. (2025) focuses specifically on global firms, gathering their views on nature risk exposure, management practices, and investor interest.

[6] This response rate is comparable to that in other surveys used by finance researchers, such as 7.5% in Stroebel & Wurgler (2021) and 2.5-4% in Giglio, Maggiori, Stroebel & Utkus (2021)

About 70% of respondents rated both physical and transition risks as at least moderately financially material. Roughly 20% believe these risks are already materializing, with transition risks generally expected to emerge earlier than physical risks.

Appendix Table A.2 shows several responses to an open-ended question asking if there were any particular ways in which biodiversity risks are important in participants' professional lives. Respondents mentioned both physical risks ("I co-run an investment fund in farmland and timberland, which are directly affected by these risks") and transition risks ("Regulatory risk related to biodiversity are a chief driver of long-term uncertainty in the energy markets in which I work"). Many survey participants discussed mechanisms through which biodiversity loss affects the economy, for example through the exposures of specific industries (as in the examples above), or at the aggregate level (as in the following responses: "Biodiversity risks are a serious threat to financial stability and the resilience of financial companies"; "Loss of biodiversity and area for animals to move closer to cities, causing a great chance for diseases to spread to humans, which may cause another pandemic").

1.2 Measuring Aggregate Biodiversity Risk

Table 1 suggests a substantial degree of concern about biodiversity risks across respondents with a wide range of backgrounds. In this section, we construct a new index that allows us to measure attention and concern related to biodiversity risks over time.

While biodiversity loss can have large economic costs, it is a slow-moving process, with many of the most severe outcomes materializing over decades (see Magurran 2021). This makes it difficult to quantify biodiversity risks or to measure assets' exposures to them. To address this challenge, we build on the insights of Engle et al. (2020), who argue that when dealing with long-term risks such as climate change or biodiversity loss, exposures can be studied through higher-frequency measures of *news* about or attention to future damages (see also Ardia et al. 2023, Stecula & Merkley 2019, Alekseev et al. 2024). Based on this idea, we construct an index of biodiversity *news* as reported in the *New York Times* (NYT).

The NYT Biodiversity News Index. The first step to building our measure of biodiversity news is to identify news articles that cover biodiversity. To do so, we build a Biodiversity Dictionary that contains 100 words common in discussions related to biodiversity loss (see Appendix Table A.3). These words were selected based on their cosine similarity to the term "biodiversity" in Google's *word2vec* implementation.[7] Using this dictionary, we identify a sentence as biodiversity-related if it contains at least one of these terms, excluding instances

[7] We use the pre-trained vectors trained on part of Google News dataset (about 100 billion words). The model contains 300-dimensional vectors for 3 million words and phrases.

Table 1: Biodiversity Risk Perceptions

		Role			Location				Biodiversity Concern			
	Pooled	Academic Institution	Private Sector	Public Sector	North America	Europe	Asia	ROW	Very High	High	Low	No Concern
Physical Risk Importance (%)												
Not at all important	8	9	9	5	9	6	9	6	1	3	9	100
Slightly important	24	26	23	20	26	20	26	14	6	27	91	0
Moderately important	35	37	28	40	34	36	38	26	19	69	0	0
Very important	34	28	40	35	31	38	28	54	73	0	0	0
Transition Risk Importance (%)												
Not at all important	7	7	6	11	8	6	7	9	1	1	9	100
Slightly important	20	22	19	18	22	19	19	11	8	17	91	0
Moderately important	42	46	34	46	40	50	36	40	26	82	0	0
Very important	30	25	41	25	30	25	38	40	66	0	0	0
Physical Risk Materialization (%)												
Already today	23	18	29	24	24	18	19	29	32	15	12	13
1 to 5 years	10	8	10	14	9	9	5	23	11	9	8	7
5 to 30 years	46	51	43	41	45	52	43	43	45	57	36	7
More than 30 years	17	18	14	19	17	17	22	3	10	17	35	30
Never	5	6	4	1	4	4	10	3	1	2	9	43
Transition Risk Materialization (%)												
Already today	20	16	27	17	23	14	16	23	27	14	15	10
1 to 5 years	26	28	25	24	25	29	22	34	33	23	15	7
5 to 30 years	41	44	34	47	40	44	43	34	33	54	41	13
More than 30 years	8	7	10	7	9	7	9	3	4	7	20	27
Never	5	5	4	6	3	7	10	6	2	2	9	43

Note: For the first two blocks, participants were asked: "Biodiversity risks for investors and firms are often divided into (i) physical risks coming from actual changes in biodiversity (e.g., reduced pollinators, freshwater scarcity) and (ii) transition risks coming from changes in the regulatory environment to combat biodiversity loss (e.g., the Clean Water Act). Please rate the financial materiality of these risks for corporations in the United States. 1- Physical Risk; 2- Transition Risk". For the last two blocks, participants were asked: "Over what time horizon, if any, do you expect these biodiversity risks to materialize?", where biodiversity risk is either the physical risk or transition risk. The percentage breakdowns in the table are to be read in columns within blocks. Biodiversity concern is defined as the maximum of a respondent's ratings for physical and transition biodiversity risk importance.

of unrelated combinations such as "software ecosystem" (see Appendix A.4 for details) and excluding the word "climate change" to allow us to capture biodiversity news separate from climate news.[8] We identify articles containing at least two 'biodiversity-related sentences' as covering biodiversity.

News about biodiversity loss can either be positive or negative; for example, an article can report that biodiversity loss is progressing faster or slower than previously anticipated. To separately identify such news stories, we adopt the Bidirectional Encoder Representations from Transformers (BERT) model to classify each of the selected biodiversity sentences to determine whether it expresses a positive or negative sentiment (Devlin et al. 2018). Sentences with positive sentiment get assigned a score of "+1", negative sentences get assigned a score of "-1", and neutral sentences get assigned a score of "0". For example, the following sentence gets classified as having a positive sentiment: *"Populations soon rebounded, improving water quality and bringing more whales, sharks, rays, seals, dolphins and other animals closer to the beach than they've been since the middle of the last century."* In contrast, a negative sentiment is assigned to *"Environmental problems remain, including overfishing and the erosion and deforestation left from earlier eras."* Appendix Table A.7 presents further examples of biodiversity related sentences alongside their BERT sentiment classifications. We assign an article to have positive (negative) sentiment if the average sentence sentiment score for all biodiversity sentences in the article is positive (negative). About 8.4% of articles get classified as positive, 72.0% as neutral, and 19.6% as negative.

To measure the overall sentiment of biodiversity news on a given day, we construct the NYT-Biodiversity News Index as the number of negative biodiversity articles minus the number of positive biodiversity articles on that day. Therefore, higher values of the NYT-Biodiversity News Index correspond to more negative news about biodiversity risks. Since news related to biodiversity risk is relatively infrequent, we generally aggregate this daily measure of biodiversity news to the monthly levels by averaging daily values over the month.

Figure 1 plots the monthly NYT-Biodiversity News Index and adds labels to events relevant to biodiversity loss. The index spikes around salient biodiversity-related events, such as changes to the Endangered Species Act (ESA) in 2019 and the release of biodiversity-

[8]We test the robustness of the index by constructing three additional indices: one using all 100 terms from the Biodiversity Dictionary, one using terms from the Biodiversity Dictionary excluding those in the Climate Dictionary (Appendix Table A.4), and one excluding terms in the Climate Change Dictionary (Appendix Table A.5). Terms in red are the common terms that are related to both biodiversity and climate/climate change. Appendix Table A.6 presents the monthly correlations across these indices. The index using all terms is highly correlated with climate risk measures due to its inclusion of the commonly-covered term 'climate change', whereas the indices excluding climate-related terms show lower correlations with climate risk. This finding highlights the importance of removing words related to climate change from the biodiversity dictionary. The high correlation among the three indices that implement such a removal indicates the robustness to the exact keywords that are excluded.

Figure 1: NYT-Biodiversity News Index

Note: Monthly NYT-Biodiversity News Index from 2010 to 2023, annotated with biodiversity-relevant news announcements. ESA: Endangered Species Act. Higher values correspond to more negative news.

related reports. There are also events with positive news about biodiversity risks, leading to a negative biodiversity news index; these include articles on the thriving of previously-threatened coyotes, foxes, and sea turtles. We have explored other ways of constructing our biodiversity news index, for example by measuring an article's sentiment as the average sentiment of all biodiversity-related sentences in that article, and by measuring the per-period overall biodiversity sentiment as the average sentiment of all biodiversity-related articles. Our key results are similar using these alternative approaches to constructing the aggregate biodiversity news index.

Text-based measures of biodiversity risk have several limitations. First, any keyword selection might lead researchers to omit relevant terms or include unrelated contexts, introducing noise. We assess the robustness of our methodology by constructing alternative NYT-based indices with different keyword sets and find high correlations across the different indicies (Appendix Table A.6). Second, machine learning models are prone to misclassification. To evaluate accuracy of our approach, we manually classified the sentiment of 100 randomly chosen biodiversity-related sentences from the NYT. The 'confusion matrix,' reported in Panel A of Appendix Table A.9, shows an average precision (the probability that a human classifier agrees with a classification made by the machine) of 81.42% and recall (the probability that the machine classifier agrees with the classification made by the human classifier) of 73.83%. We report misclassification examples in Appendix Table A.10. Appendix

Table A.11 shows the 100 sentences for which we compared the machine classification to the human classification, which can provide a sense of the ambiguities involved in the classification. Reassuringly, while there are several examples in which human classification and machine classification disagree in whether a sentence is negative or neutral (or positive or neutral), there are no examples where a sentence with a negative classification by one party is assigned a positive classification by the other party.

1.3 Biodiversity Risk vs. Climate Risk

As discussed above, climate and biodiversity risk are related but distinct concepts. In this section, we explore the relationship between the two risks quantitatively, by comparing our biodiversity risk series with a corresponding climate risk series.

To do this, we first build a new climate news series, the NYT-Climate News Index, by applying the methodology described in Section 1.2, identifying climate-related sentences with the terms "climate change" and "global warming." As alternatives to our own climate news series, we also consider four of Faccini et al. (2023)'s climate news indices: international climate summits, global warming, natural disasters, and the climate policy index. These indices are designed to capture news about the respective topics, which correspond to different aspects of climate risk. These measures, which cover news about both physical and transition climate risks, are available at a daily frequency between January 2000 and June 2023. We aggregate them to the monthly frequency by taking the average of the daily series.

Table 2: Correlation Across Measures of Aggregate Risk

	(1)	(2)	(3)	(4)	(5)	(6)
Biodiversity Risk Measures						
(1) NYT-Biodiversity News	1.00					
Climate Risk Measures						
(2) NYT-Climate News	0.43	1.00				
(3) Faccini et al (2023): International Summit	−0.11	−0.14	1.00			
(4) Faccini et al (2023): Global Warming	0.10	0.51	0.21	1.00		
(5) Faccini et al (2023): Natural Disaster	0.21	0.64	−0.06	0.41	1.00	
(6) Faccini et al (2023): Climate Policy	0.20	0.50	0.11	0.76	0.41	1.00

Note: Pairwise monthly correlation across biodiversity and climate risk measures. NYT-Biodiversity News and NYT-Climate News use data from January 2010 to December 2023, while Faccini et al (2023) indices span from January 2010 to June 2023.

Table 2 shows the pairwise correlation across these various news indices using monthly data from 2010 to 2023. The first column is the NYT-Biodiversity News Index, the next column is the NYT-Climate News Index and the last four columns are the Faccini et al. (2023) indices. The correlation between the biodiversity news index and the five climate news indices ranges

between -0.11 and 0.43. These results suggest that while climate risk and biodiversity news are related to some extent, they are not the same.

Figure 2 illustrates the differences between the biodiversity and climate news series. The solid black line and black annotations correspond to the NYT-Biodiversity News Index and related biodiversity risk events, while the dotted grey line and grey annotations correspond to the NYT-Climate News Index. Note that both series are generated with the same method and based on the same data: articles published in the New York Times; they differ only in the keywords used to select the articles.

Figure 2: NYT-Biodiversity News vs NYT-Climate News

Note: Monthly NYT-Climate News Index from 2010 to 2023, overlaid against the NYT-Biodiversity News Index and annotated with relevant news announcements. Higher values correspond to more negative news.

Months with negative biodiversity-related news do not necessarily correspond to months with negative climate news. For example, in August 2019, the Trump administration announced that it would change the way the Endangered Species Act was applied, making it easier to remove a species from the endangered list and weakening protections for threatened species. This led to substantial negative newspaper coverage of biodiversity-related topics, and thus a sharp increase in the NYT-Biodiversity News Index, while the NYT-Climate News Index remained relatively stable. Similar events include the 2010 Gulf Coast oil spill, which increased risks to various ecosystems. Conversely, climate-related events, such as the withdrawal from the Paris Agreement and discussion on carbon tax did not result in spikes in the biodiversity news index. Finally, some natural disasters were followed by both negative climate and neg-

ative biodiversity news: for example, the 2023 Hawaii Wildfires were connected to climate change but also caused habitat and species loss. Similarly, the release of the Global Biodiversity Outlook report, highlighting climate change as a driver of biodiversity loss, resulted in spikes in both climate change and biodiversity news.

2 Measuring Biodiversity Risk Exposures

Beyond quantifying aggregate biodiversity risk, we are also interested in exploring how biodiversity risk exposures vary across different firms and industries. For instance, the World Economic Forum (2022) states that the three sectors most reliant on natural capital are construction, agriculture, and food & beverages. Based on this assessment, firms in those sectors would be most substantially exposed to physical biodiversity risks. Similarly, sectors with substantial land use, such as the energy sector, might be particularly impacted by biodiversity transition risks. To improve our understanding of the effects of biodiversity risk on the economy, we need a systematic way to quantify these cross-sectional risk exposures.

A number of data vendors provide measures of firms' physical and transition *climate* risk exposures, though there are substantial questions about the quality of these measures (see, for example, Billio et al. 2021). Similar data for firms' biodiversity risk exposures are not broadly available and standardized disclosure frameworks for biodiversity risk are still under development (Taskforce on Nature-related Financial Disclosures 2024).[9]

In this section, we therefore propose and compare several new ways to measure firms' biodiversity risk exposures, using different data sources: (i) firms' 10-K statements; (ii) the opinions elicited in our survey of financial professionals, academics, and regulators; (iii) the portfolio holdings of funds focused on biodiversity; and (iv) firms' responses to the CDP Climate Change Questionnaire, which recently added a module focused on biodiversity risks. The first measure is available at the firm level, the others only at the industry level. We publicly release our measures of biodiversity risk exposure at `www.biodiversityrisk.org`. In additional analyses in the Appendix, we report results from an attempt to distinguish between transition risk and physical risk by exploiting recent large language models (GPT-4.0) to parse the text of the NYT as well as that of the 10-K statements.

[9]Some data providers have begun to offer tools for biodiversity impact assessments, as summarized by Finance for Biodiversity Foundation. Examples include the Biodiversity Footprint for Financial Institutions (BFFI), the Biodiversity Impact Analytics powered by the Global Biodiversity Score (BIA-GBS), the Corporate Biodiversity Footprint (CBF), the Global Biodiversity Score for Financial Institutions (GBSFI), and the Global Impact Database (GID), the Exploring Natural Capital Opportunities, Risks and Exposure (ENCORE) database, and the Integrated Biodiversity Assessment Tool (IBAT).

2.1 Measures of Biodiversity Risk Exposure of Firms and Industries

10K-Biodiversity-Count Score. Our first firm-level measure of biodiversity risk exposure is based on textual analysis of firms' 10-K statements.[10] We identify biodiversity-related sentences in 10-K statements using regular expression searches for the same biodiversity dictionary used to construct the NYT-Biodiversity News Index, again excluding sentences with unrelated terms. If a 10-K statement contains at least two sentences related to biodiversity, we assign a 10K-Biodiversity-Count Score of "1" to this company in that year; if there is no mention of biodiversity-related terms, we assign a score of "0". We find that about 4.2% of all 10-K statements mention biodiversity between 2015 to 2023. The following are two examples of biodiversity-related sentences from 10-K statements, the first referencing transition risk exposures, and the second referencing physical risk exposures.

> In addition, future regulation of, or litigation concerning, the use of timberlands, the protection of endangered species, the promotion of forest biodiversity, and the response to and prevention of wildfires, as well as litigation, campaigns, or other measures advanced by environmental activist groups, could also reduce the availability of the raw materials required for our operations. [Enviva Partners LP, 2017 10-K filing]

> If this infrastructure were to become damaged due to natural or other disasters such as the oil spill that resulted from the Deepwater Horizon incident in 2010, then it is possible that environmental damages to the area and ecosystem could result. If these environmental damages occurred, they could have a material adverse effect on the Company's business, results of operation, and financial condition. [Omega Protein, 2015 10-K filing]

10K-Biodiversity-Negative Score. The 10K-Biodiversity-Count Score combines mentions of biodiversity as both a risk and an opportunity for firms. To separate such mentions, we construct a second measure of biodiversity risk exposure, the 10K-Biodiversity-Negative Score, based on sentiment analysis of the 10-K sentences mentioning biodiversity-related terms. Specifically, we use the BERT model to classify each biodiversity-related sentence into positive, neutral, and negative sentiments. The two previous 10-K excerpts are assessed

[10] A 10-K statement is a comprehensive report filed annually by publicly listed companies with the U.S. Securities and Exchange Commission (SEC). It provides a detailed overview of a company's performance, including both structured financial metrics and unstructured textual information, such as management's discussion and analysis, business overview, and risk factors. We collect firms' 10K statements from 2001 to 2023 through the SEC's EDGAR database.

to have a negative sentiment by BERT; the following are two examples of a biodiversity-related 10-K mention that received a positive sentiment classification from BERT (Appendix Table A.8 presents further examples).

> We believe that the growth of hemp could significantly reduce deforestation by providing the same products that trees are able to supply. [Celexus Inc, 2019 10-K filing]

> The Company follows Sustainable Forestry Initiative ('SFI') Standards that promote sustainable forest management in North America through the use of core principles, objectives, performance measures and indicators to protect water quality, biodiversity, wildlife habitat, species at risk, and forests which have exceptional conservation value. [Deltic Timber Corp, 2017 10-K filing]

About 5.4% of biodiversity-related sentences are classified as positive, 19.4% as negative, and the remaining as neutral. For each firm-year, we count the number of positive and negative sentences and compute the firm 10K-Biodiversity-Negative Score as the number of negative biodiversity sentences minus the number of positive sentences (firms that do not mention biodiversity-related topics in their 10-K statement and firms that only include neutral sentences are assigned a score of 0). Between 2015 and 2023, among 10-K statements mentioning biodiversity-related issues, 27.6% do so in a predominantly negative way and 5.6% in a predominantly positive way.

10K-Biodiversity-Regulation Score. When firms mention biodiversity in their 10-K statements, some explicitly express their concerns about the biodiversity risks stemming from stricter regulations. To directly measure these regulation-related biodiversity risks faced by firms, we construct a third 10-K-based measure that selects biodiversity risk sentences that also contain at least one of the following terms: "law(s)," "regulation," "Act," "ESA," "discharge," or "restriction." Appendix Table A.8 shows several examples of such sentences. We assign a 10K-Biodiversity-Regulation Score of "1" if the 10-K statement of a company contains at least two biodiversity risk sentences and at least one of them is a biodiversity regulation risk sentence. Between 2015 and 2023, about 3.2% of all 10-K reports (and 75.5% of all 10-K reports discussing biodiversity) discuss biodiversity-related regulation risks.

Just as we did for the NYT classification, we validate the machine classification of the 10-K statements. To do this, we manually classify 100 randomly chosen biodiversity-related sentences from the 10-K filings, and assess sentiment classification (10K-Negative Score) and policy relevance (10K-Regulation Score). The confusion matrices in Panels B and C of

Appendix Table A.9 show an average precision of 83.61% and recall of 78.6%, with misclassification examples in Appendix Table A.10. As before, there are no examples where one classifier assigns it a label of negative sentiment and the other a positive sentiment.

Survey-Based Measures of Biodiversity Risk Exposures. We construct another measure of biodiversity risk exposures—this time at the industry level—based on responses received in our survey of finance academics, professionals, and regulators. The survey asked participants to select the industries that they believe to be most negatively affected by (i) physical risks arising from biodiversity loss, and (ii) biodiversity-related transition risks (see Appendix Figure A.4). We provided 15 possible industry options to choose from, created by combining several of the 24 4-digit GICS industries.[11] We quantify an industry's physical and transition biodiversity risk exposure as the share of survey respondents who select each industry as being particularly affected by the risk.

Holding-Based Measure of Biodiversity Risk Exposures. In response to growing concerns about the economic effects of biodiversity loss, some asset managers have introduced investment vehicles designed to help investors mitigate biodiversity risks in their portfolios. Our next approach to measuring biodiversity risk exposures builds on information about the holdings of these funds. To construct the Holding-based Biodiversity score, we explore five biodiversity-related funds: HSBC World ESG Biodiversity Screened Equity ETF, AXA IM ACT Biodiversity Equity ETF, Ossiam Food for Biodiversity ETF, Xtrackers World Biodiversity Focus SRI UCITS ETF, and Xtrackers USA Biodiversity Focus SRI UCITS ETF. These biodiversity ETFs were designed to hold companies that are acting positively for biodiversity by reducing or limiting the negative impact of human activities on biodiversity.

We obtain data on these funds' portfolio holdings from Bloomberg and focus on North American common stocks. We obtain prices from CRSP and GICS industry codes[12] from Compustat by merging the stocks on their CUSIP identifiers. We define the holding-based biodiversity score of fund f for industry I as:

$$HoldingScore^{I}_{t,f} = \frac{w_{I,t,M} - w_{I,t,f}}{w_{I,t,M}}, \tag{1}$$

[11]Specifically, Automobiles & Components (GICS code 2510), Consumer Durables & Apparel (GICS code 2520), and Household & Personal Products (GICS code 3030) are pooled into "Auto, Durables and Household Products". Consumer Services (GICS code 2530), Retailing (GICS code 2550), and Food & Staples Retailing (GICS code 3010) are pooled into "Consumer Services and Retailing". Banks (GICS code 4010) and Diversified Financials (GICS code 4020) are pooled into "Banks and Diversified Financials". Software & Services (GICS code 4510), Technology Hardware & Equipment (GICS code 4520), Semiconductors & Semiconductor Equipment (GICS code 4530), Telecommunication Services (GICS code 5010), and Media & Entertainment (GICS code 5020) are pooled into "IT and Communication Services."

[12]We used the GICS 2023 classification and did not adjust for any GICS changes.

where $w_{I,t,M}$ is the weight of industry I in the market portfolio at time t and $w_{I,t,f}$ is the weight of industry I in the fund's portfolio (i.e., based on the industry's market capitalization).[13] When a fund underweights an industry relative to the market, the score will be positive: we interpret this as the industry being negatively exposed to biodiversity risk in the sense that it should perform relatively poorly upon the realization of negative biodiversity news. We compute this score for each fund and then average across funds to get the industry-level holding-based score (the average pairwise correlation of $HoldingScore^{I}_{t,f}$ across the funds is 0.31). Since these ETFs were set up relatively recently, we only use data from December 2023.

CDP-Based Measure of Biodiversity Risk Exposures. Our final measure of biodiversity risk exposure uses responses obtained from the CDP Climate Change Questionnaire. Questions related to biodiversity risk exposures have been included since 2022, and are shown in Appendix Figure A.7. To quantify a firm's exposure to biodiversity risks, we assign a score of "1" if the firm has activities in or near biodiversity-sensitive areas and the activity could negatively affect biodiversity; otherwise, we assign a score of "0". We focus on the responses of U.S. firms. A total of 633 firms participated in the biodiversity module, with 4.9% of these firms having activities with negative impact located in or near biodiversity-sensitive areas. We aggregate the firm-level exposure measures to the industry level by calculating the value-weighted average of the firm-level scores.

2.2 Biodiversity Risk Exposures Over Time

While we can only construct the survey-, holdings-, and CDP-based measures of biodiversity risk exposures at one point in time, the availability of historical 10-K statements allows us to construct a time series of firms' self-reported exposures to biodiversity risks.

Figure 3 shows our three 10K-based biodiversity risk exposure measures between 2001 and 2023, averaged across all firms in each period. Across all firms, self-reported biodiversity risk exposures have generally been growing over time, from about 1% of firms mentioning biodiversity-related terms in the early 2000s, to a peak of almost 5% of firms in 2023. This increase is largely driven by a corresponding increase in the number of mentions of biodiversity regulation risks. Consistent with this, the sentiment with which firms discuss biodiversity-related issues has declined over time.

[13] This measure does not differentiate between neutral and negatively exposed firms, as the biodiversity-focused funds we study are long-only. As a result, industries excluded from biodiversity funds—whether neutral or harmful—all receive the same weight $w_{I,t,f} = 0$, and the same HoldingScore of 1.

Figure 3: Proportion of Biodiversity-Related Mentions in 10-K Over Time

Note: This figure shows the share of firms with non-zero biodiversity-related mentions in their 10-K statements from 2001 to 2023. The solid line indicates firms mentioning biodiversity (10K-Biodiversity-Count Score); the dotted line shows negative biodiversity sentiment (10K-Biodiversity-Negative Score); and the dashed line captures mentions to biodiversity-related regulation (10K-Biodiversity-Regulation Score). Shares are calculated by dividing the number of firms with non-zero scores by the total number of firms filing a 10-K each year.

2.3 Biodiversity Risk Exposures Across Firms and Industries

In this section, we compare biodiversity risk exposures across firms and industries. First, we examine the extent to which firm characteristics drive biodiversity risk exposure. To do this, we proxy for firm-level biodiversity exposure using the average of the three 10K-based measures and regress that measure on firm size (log assets) and market-to-book ratio:

$$\text{Biodiversity Exposure}_{i,t} = \alpha + \beta_i^{Size}\text{Size}_{i,t} + \beta_i^{MB}\text{MB}_{i,t} + \delta_t + \gamma_g + \epsilon_{i,t}. \tag{2}$$

Table 3 shows the regression results. Biodiversity exposure is negatively associated with the market-to-book ratio, suggesting that growth firms face lower exposure than value firms. Larger firms also exhibit greater biodiversity risk. However, these characteristics explain only 1% of the variation in firm-level biodiversity risk exposures. Including industry fixed effects increases the R-squared by 11 percentage points. When including industry and year fixed effects, the relationship between size and biodiversity exposure disappears.

Comparison Across Different Measures. Next, we compare the biodiversity risk exposures of different industries across our various measures. For this analysis, we aggregate the 10K-based firm-level exposure measures to the industry level by calculating the value-

Table 3: Firms Characteristics and Biodiversity Exposure

	Biodiversity Exposure		
	(1)	(2)	(3)
Log Assets	0.005***	0.001	-0.001
	(4.66)	(1.32)	(-1.13)
Market to Book	-0.002***	-0.000**	-0.001**
	(-5.73)	(-2.23)	(-2.21)
Year FE	No	No	Yes
Industry FE	No	Yes	Yes
N	49,184	49,184	49,184
R-squared	0.01	0.12	0.13

Note: This table reports regressions of biodiversity exposure on firm characteristics. Biodiversity Exposure is the average of 10K-Biodiversity-Count, 10K-Biodiversity-Negative, and 10K-Biodiversity-Regulation Scores. Regressions are estimated at the firm-year level. Standard errors are clustered at the firm level. T-statistics are in parentheses. Significance levels: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

weighted average of the firm-level scores. Table 4 reports the cross-industry correlations of biodiversity exposures according to the different measures. We use 10-K statements from 2015 to 2023 to do the cross-sectional comparison. The table highlights that our industry-level measures of biodiversity risk exposures are substantially correlated: industries that are assessed to have high biodiversity risk exposures on one measure also have high exposures using the other measures.

Panel (a) of Figure 4 shows the biodiversity risk exposures of different industries. To construct this figure, we first rank each industry from least exposed (rank = 1) to most exposed (rank = 24) on each of our measures, and then average the ranks across our measures.[14] The sectors with the highest average biodiversity risk exposures are Energy, Utilities, Real Estate, Food, Beverage & Tobacco, and Pharmaceutical, Biotechnology & Life Sciences. This ranking aligns with economic intuition, as these highly ranked sectors are all directly dependent on natural resources.[15] On the other hand, firms in the Communication Services,

[14] Appendix Figures A.6 show the industry-level exposure measures separately for each of our measures. Appendix Table A.12 reports the industry rankings for each measure. The industries are sorted by their average ranking across the seven measures, excluding the "Survey: Average" score. Industries at the top are most exposed to biodiversity risk, while those at the bottom have the lowest exposure to biodiversity risk.

[15] This pattern is consistent with Nature Action 100's sectoral impact assessments (Finance for Biodiversity Foundation 2023), which use footprinting tools to identify industries with the greatest biodiversity impact. Their rankings place Food, Beverage & Tobacco, Materials, Energy, Capital Goods, Retailing, Utilities, and Pharmaceuticals in the top 7 riskiest industries. The high exposure of Energy and Utilities in particular reflects well-documented biodiversity risks from fossil fuel extraction and infrastructure projects. The Deepwater Horizon oil spill, for example, caused lasting ecological damage, while hydropower projects like Brazil's Belo Monte Dam have disrupted aquatic habitats. Pharmaceuticals rely on biodiversity for drug discovery, as seen in the near-extinction of the Pacific Yew tree, which threatened the supply of paclitaxel (Taxol), a key cancer drug. In the Food, Beverage & Tobacco sector, pollinator declines have already reduced yields for crops like coffee, cocoa, and almonds, highlighting the sector's dependence on ecosystem stability.

Table 4: Industry-level Correlations of Biodiversity Scores

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
10k-based Scores									
(1) 10k: Negative	1.00								
(2) 10k: Count	0.70	1.00							
(3) 10k: Regulation	0.80	0.96	1.00						
Survey-based Scores									
(4) Survey: Transit.	0.53	0.42	0.42	1.00					
(5) Survey: Physical	0.26	0.20	0.18	0.82	1.00				
(6) Survey: Average	0.41	0.32	0.31	0.95	0.96	1.00			
Holding-based Scores									
(7) Holding	0.39	0.03	0.22	0.27	0.08	0.18	1.00		
CDP-based Scores									
(8) CDP-based	0.89	0.87	0.91	0.58	0.30	0.46	0.29	1.00	
Climate Exposure Scores									
(9) Quantity-based	0.05	0.01	0.05	−0.15	0.16	0.01	−0.01	−0.10	1.00

Note: Industry-level Pearson correlations of 10K-based, Survey-based, Holding-based, CDP-based Biodiversity Scores, and Quantity-based Climate Exposure Score. The 10K-based Biodiversity Scores are averaged from 2015 to 2023. Survey-based Scores are from Q1 2023. Holding-based Score is from Q4 2023. CDP-based Score uses data from 2023. The Quantity-based Climate Exposure Score is estimated with data from 2010 to 2019 inclusive, and is taken from Alekseev et al. (2024).

Software, and Technology sectors—firms which have minimal direct interaction with natural ecosystems—appear the least exposed to biodiversity risks.

Panel (b) of Figure 4 separately shows physical and transition risk exposures across industries as elicited in our survey.[16] Our survey participants perceive distinct heterogeneities among industries in terms of their biodiversity risk exposures: industries that are perceived to be exposed to physical biodiversity risks are not necessarily the same as industries that are perceived to be exposed to transition biodiversity risks, though the two measures are substantially correlated. For example, our respondents perceive the "Food, Beverage & Tobacco" sector to be most exposed to physical biodiversity risks, and the "Energy" sector most exposed to transition biodiversity risks.

To better understand the observed variation in biodiversity risk exposures across industries, we next consider the top industries in terms of average risk exposures and discuss the ways in which biodiversity risks affect those industries. To help with these interpretations, Appendix Figure A.8 provides word clouds with the terms that are most frequently mentioned in biodiversity-related sentences extracted from 10-K statements for each industry,

These examples illustrate the strong link between industry activities and biodiversity risk exposure that are consistent with our more systematic assessments of industry-level exposures.

[16] Appendix Table A.13 shows the correlations of average industry rankings across different groups of survey respondents. The rankings are similar across subgroups, with the correlation ranging from 0.82 to 0.99. For example, the pairwise correlations between industry rankings reported by academics, private-sector employees, and public-sector employees are above 0.95.

Figure 4: Industry-Level Biodiversity Risk Exposure

Note: Panel (a) shows the average industry exposure ranking based on the simple average of all biodiversity risk measures. The 10K-based Biodiversity Scores are averaged from 2015 to 2023. Survey-based Scores are from Q1 2023. Holding-based Score is from Q4 2023. CDP-based Score uses data from 2023. Panel (b) presents physical and transition risk exposures measured by survey responses. The blue bars represent survey-based physical risk, while the red bars indicate survey-based transition risk. Industries are sorted by the average of these two survey-based measures.

with term sizes proportional to their frequency.[17] Appendix Figure A.9 shows the biodiversity risk exposure disaggregated to 6-digit GICS industry codes. Appendix A.4.4 provides further discussion on how biodiversity risks impact industries with high exposure, including materials and real estate sectors.

Energy Sector. Our survey respondents assessed firms in the energy sector to have the highest biodiversity transition risk due to the potential impact of energy firms' operations on biodiversity. For instance, oil spills and habitat destruction during drilling activities can lead to the loss of species and ecosystems, and entail substantial reputational and legal risks. The industry also faces regulatory risks, as governments introduce stricter environmental regulations and guidelines to prevent further biodiversity loss. Examples of firms in the energy sector describing such biodiversity risk exposures in their 10-K statements include:

> If one of our LNG terminals or pipelines may adversely affect a protected species or its habitat, we may be required to develop and follow a plan to avoid those impacts. [Cheniere Energy Inc, 2024 10-K filing]

> A critical habitat designation could result in further material restrictions on federal land use or on private land use and could delay or prohibit land access or development. [Earthstone Energy Inc, 2019 10-K filing]

Utilities. Firms in the utilities sector are affected by both physical and transition biodiversity risks. Physical risks matter, for example, when the degradation of watersheds affects water quality and availability, which in turn impacts water utilities. On the transition risk side, regulations and laws on species and habitat protection may limit utility firms' operations. In addition, regulations on waste discharges, such as the Clean Water Act, elevate utility firms' costs, especially those in water utilities.

Interestingly, firms producing renewable electricity—often viewed as beneficiaries of the climate transition—have among the most negative biodiversity risk exposures within the utilities sector (Appendix Figure A.9). This reflects the land-intensive nature of constructing wind and solar power facilities, which makes them subject to stringent land-use regulations aimed at protecting biodiversity. Additional regulations affect specific renewable sources: hydropower development is constrained by rules protecting fish populations, while wind projects face restrictions related to the unintentional killing of migratory birds.

[17] To plot the word cloud, we extract biodiversity sentences using the same Biodiversity Dictionary for companies within each sector and aggregate these sentences into a "Biodiversity Vocabulary", which amounts to the list of unique terms and the associated frequency with which each term appears.

> Our ability to meet the existing and future water demands of our customers depends on an adequate supply of water. Drought, governmental restrictions, overuse of sources of water, the protection of threatened species or habitats or other factors may limit the availability of ground and surface water. [American Water Works Company Inc, 2015 10-K filing]

> The Company is also subject to laws regarding the protection of wildlife, including migratory birds, eagles, threatened and endangered species. Federal and state environmental laws have historically become more stringent over time, although this trend could change in the future. [Clearway Energy Inc, 2022 10-K filing]

Real Estate. The real estate industry is exposed to various biodiversity risks. For example, developments in areas with high biodiversity might face restrictions or require mitigation measures to minimize habitat destruction, adding costs and delays to projects.

> The sale or development of properties may also be restricted due to environmental concerns, the protection of endangered species, or the protection of wetlands. [St Joe Co, 2002 10-K filing]

Food, Beverage, and Tobacco. The food industry faces significant physical biodiversity risks due to its dependence on biodiversity for essential raw materials.

> Physical risks include the increasing frequency of extreme weather events and natural disasters and effects on water availability and quality and biodiversity loss. These impacts increase risks to the global food production and distribution system and to the safety and resilience of the communities where we live, work and source our ingredients, and could further decrease food security for communities around the world. [Mondelez International Inc, 2022 10-K filing]

> Climate change, agricultural and other factors, such as wildfires, disease, pests, extreme weather conditions, water scarcity, biodiversity loss and competing land use, impact the quality and quantity of grapes available to us for the production of wine from year to year. Our vineyards and properties, as well as other sources from which we purchase grapes, are affected by these factors. [Vintage Wine Estates, 2023 10-K filing]

Pharma and Biotech. The Pharmaceuticals, Biotechnology & Life Sciences sector is exposed to substantial physical biodiversity risks. For example, in the last 40 years, about 60% of all new chemical entities in the field of antibacterials were based on or derived from natural products (Newman & Cragg 2020). Biotechnology companies establish natural product libraries of microorganisms retrieved from soil, plant, and marine sources for drug discovery. Biodiversity loss therefore reduces potential pharmaceutical development options.

> Other potential physical impacts due to climate change include reduced access to high-quality water in certain regions and the loss of biodiversity, which could impact future product development. These risks could disrupt our operations and its supply chain, which may result in increased costs. [Iovance Biotherapeutics Inc, 2022 10-K filing]

> We focus on the use of biodiversity as a means of natural product drug discovery, while also using traditional chemical discovery and development techniques. [Cubist Pharmaceuticals Inc, 2000 10-K]

2.4 Climate Risk Exposures vs. Biodiversity Risk Exposures

Just as aggregate biodiversity news is distinct from aggregate climate news (see Section 1.3), firm- and industry-level exposures to biodiversity risk are distinct from climate risk exposures. The bottom row of Table 4 shows that our measures of biodiversity risk exposure at the industry level are essentially unrelated with the "quantity-based climate exposure" measure developed in Alekseev et al. (2024). This measure identifies industries that investors buy and sell in response to changes in their beliefs about climate change, and Alekseev et al. (2024) show that long-short portfolios based on this exposure characteristic have the ability to hedge news about climate risks. Figure 5 shows a corresponding scatter plot, where biodiversity risk exposure is measured by the average ranking across our seven biodiversity risk measures, excluding the "Survey: Average" score. A higher ranking indicates higher risk.

Industries with high biodiversity risk exposures are broadly distinct from industries with high climate risk exposures. There are several reasons for this. First, an industry may be highly exposed to biodiversity risk because its operations are dependent on particular ecosystems or species that are not necessarily affected by climate change. Second, from a regulatory perspective, some industries might have a more significant direct impact on ecosystems and habitats rather than contributing to climate change. As a result, they would be more affected by biodiversity regulation than climate regulation. For example, as described above, biodiversity regulation provides challenges for renewable energy firms, while climate regulation provides many opportunities.

Figure 5: Industry Ranking by Biodiversity Risk and Climate Risk

Note: Scatterplot of industry biodiversity risk ranking and climate risk ranking. The biodiversity risk exposure is measured by the average ranking across the seven biodiversity risks, excluding the "Survey: Average" score, and the climate risk exposure is measured by climate quantity betas estimated based on pooled data from 2010 to 2019 inclusive, and is taken from Alekseev et al. (2024).

3 The Pricing of Biodiversity Risk

A recent body of research in economics and finance has documented that starting around 2010, various measures of firm-level exposures to climate risk have been priced in asset markets (e.g., Bolton & Kacperczyk 2023, Engle et al. 2020, Alekseev et al. 2024, Acharya et al. 2022). In this section, we explore whether biodiversity risk—a category of risk that has also attracted the attention of market participants in recent years—appears to affect prices in equity markets. To do this, we combine our quantitative measures of aggregate news about biodiversity risk with our industry-level measures of biodiversity risk exposures.

Empirical Approach. We begin by forming portfolios of industries sorted by their biodiversity risk exposures[18]. If biodiversity risk is priced—and if our measures of exposure to this risk are correct—we would expect the price of these portfolios to move with the arrival

[18]We obtain stock-level data from CRSP and Compustat, focusing on North American common stocks (share codes 10 and 11; exchange codes 1, 2, and 3). We exclude stocks priced below $5 and the bottom 20% by market cap at each date. GICS industry codes are merged from Compustat using CUSIP identifiers.

of (aggregate) news about or attention to biodiversity risks. For example, when negative biodiversity news arrives (or when attention to this type of risk increases), the valuations of highly exposed industries should drop, while the valuations of less exposed industries should drop by less (or even increase). Put differently, if biodiversity risks are priced, we should expect the return to a biodiversity risk-sorted portfolio to covary with the aggregate biodiversity risk news series: it should behave like a *hedge portfolio*.[19]

To implement our test, we measure innovations in biodiversity news, $BiodiversityNews_t$, by averaging the daily values of our aggregate NYT-Biodiversity News Index within each month and computing values of $BiodiversityNews_t$ as residuals from a monthly AR(1) model. We then construct portfolios that go long firms with low biodiversity risk exposures—i.e., firms that are not affected or might even benefit from realizations of biodiversity risks—and short firms with high biodiversity risk exposures, those firms negatively affected by biodiversity risk realizations.[20] We construct eight such portfolios using the three 10K-based biodiversity scores, the three survey-based scores, the fund holding-based score, and the CDP-based score. We construct all portfolios using exposure measures at the industry level, aggregating the firm-level 10K-based scores to the industry level by taking the value-weighted average of the firm-level values.

To determine the portfolio weight of each industry, we take two approaches. In our main rankings-based approach, the portfolio's position in each industry is the industry's biodiversity score percentile in the industry distribution, minus 50. For example, the portfolios take a long position of 50 in the industry with the lowest biodiversity score and short a position of -50 in the industry with the highest biodiversity score.[21] We show that our findings are robust to a second approach that holds positions in each industry as the cross-sectionally demeaned biodiversity scores in that year, taking long positions for industries with below-average scores (and risk exposures), and short positions for industries with above-average scores. In each period, we compute excess returns of each portfolio by subtracting the risk-free rate from the value-weighted industry returns.

Figure 6 reports monthly correlations between the various portfolios' excess returns and innovations of the NYT-Biodiversity News index using data from 2010 to 2023.[22] We include

[19]Note that researchers sometimes refer to the presence of risk premia when asking whether a risk is "priced." That language refers to the compensation for risk required by investors, which has as a necessary (but not sufficient) condition that prices of exposed firms move with risk realizations. We focus on the latter pattern because estimating risk premia would require a much longer time series.

[20]Since all exposure measures were designed such that higher values are associated with higher biodiversity risk exposures, the portfolios would go long industries with low scores and short industries with high scores.

[21]When ranking the industries, equal observations are assigned the same rank, calculated as 1 plus the number of values lower than those equal observations.

[22]The 10-K–based portfolios are rebalanced annually using the prior year's filing to avoid look-ahead bias. In contrast, the survey-, holdings-, and CDP-based biodiversity scores are constructed at a single

Figure 6: Biodiversity Hedge Performance of Various Portfolios

Note: Dot plot of monthly return correlations for various biodiversity hedge portfolios with AR(1) innovations of NYT-Biodiversity News index using data from 2010 to 2023.

individual rank-based portfolios for our various industry exposure measures, as well as a portfolio that averages across the industry ranks in the different exposure measures before forming portfolios, a portfolio averaging the three time-varying 10-K-based industry ranks. We also include a portfolio that uses the average values of the alternative approach to creating industry weights described in the previous paragraph. We focus on the period after 2010, since we do not expect markets to price biodiversity risk before that time (see the discussion in Alekseev et al. 2024, Acharya et al. 2022). All correlations are positive, with magnitudes from around 0.07 to 0.22. The left column in Table 5 reports these correlations together with bootstrapped standard errors. It highlights that, despite substantial noise in both stock prices and our measures of biodiversity risk and risk exposures, most of these correlations are statistically significant. The largest correlation is achieved by the portfolio sorted on the average across our various biodiversity risk exposure rankings. Quantitatively, the observed correlations are comparable to those obtained by climate hedging portfolios when evaluated against aggregate climate news (Engle et al. 2020, Alekseev et al. 2024), and to the hedging performance of portfolios built to hedge other macro risks such as consumption or GDP (see Giglio & Xiu 2021).

point in time, and the portfolio weights derived from these scores remain fixed throughout the analysis. Correlations between the biodiversity hedge portfolios and biodiversity innovations are estimated over the full sample period from 2010 to 2023 using these fixed portfolio weights. Since the weights do not reflect contemporaneous risk exposure, these correlations are weaker than those of the 10-K–based portfolios.

Table 5: Biodiversity and Climate Hedge Performance of Various Portfolios

	Hedge Target	
	NYT-Biodiversity News	NYT-Climate News
Average: Rank-based Portfolio	0.22***	0.03
	(0.08)	(0.10)
10K: Regulation	0.18**	0.09
	(0.08)	(0.08)
10K: Count	0.18**	0.13*
	(0.07)	(0.07)
Average: Value-based Portfolio	0.17**	0.06
	(0.08)	(0.09)
10K: Negative	0.17**	0.09
	(0.07)	(0.08)
Holding	0.16**	0.04
	(0.07)	(0.09)
CDP	0.15*	0.08
	(0.08)	(0.09)
Survey: Transition	0.11	-0.02
	(0.07)	(0.09)
Survey: Average	0.10	-0.03
	(0.07)	(0.09)
Survey: Physical	0.07	-0.02
	(0.07)	(0.08)
Average	0.15***	0.05
	(0.05)	(0.06)

Note: Monthly correlations for various biodiversity hedge portfolios' returns with biodiversity and climate news series AR(1) innovations using data from 2010 to 2023. Each row represents a hedge portfolio, whereas each column corresponds to a hedge target. The last row shows the simple average of correlations with hedge targets for all portfolios. All news series are coded such that high numbers indicate negative news. Therefore, positive correlation coefficients indicate successful hedges. Significance levels: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. P-values are calculated using a bootstrap of 1,000 iterations. Bootstrapped standard errors are in parentheses.

A natural question is whether our measures of biodiversity risk exposure are simply recasting information from other firm characteristics beyond size and value, which we already explored above. To study this, we investigate whether using other characteristics would yield similarly good hedging portfolios for aggregate biodiversity news as the ones based on our measures of biodiversity risk exposure.

In comparing our measures of exposures with other characteristics, one important consideration is that, in general, we do not have a clear prior on whether the various characteristics should be associated with a high or low exposure to biodiversity risk. For example, we do not know ex-ante if a portfolio that goes long value companies and short growth companies (HML) should covary positively or negatively with biodiversity risk. Building a hedging portfolio using alternative characteristics therefore requires estimating the sign of the relationship between the biodiversity news and the characteristic—the biodiversity beta—using

a mimicking portfolio approach (as in Engle et al. 2020, Alekseev et al. 2024). The mimicking portfolio approach uses historical data to combine a set of assets into a portfolio that is maximally correlated with a given biodiversity shock. To obtain the mimicking portfolios, we estimate the following regression:

$$BiodiversityNews_t = wR_t + \epsilon_{c,t}, \tag{3}$$

where $BiodiversityNews_t$ denotes the (mean zero) biodiversity hedge target in month t, w is a vector of N portfolio weights, and R_t is a vector of demeaned excess returns. The portfolio weights are estimated each month using a five-year rolling window.[23] When the vector R_t contains one characteristic-sorted return only (e.g., HML), the weight w represents the relation between that characteristic and the biodiversity beta. For example, if we build a hedging portfolio using HML and estimate $w > 0$, then we expect value stocks to hedge biodiversity risk going forward; if $w < 0$, we expect growth stocks to hedge this risk.

Panel (a) of Figure 7 shows a histogram of the out-of-sample correlations of mimicking portfolios built using the 212 characteristics obtained from Chen & Zimmermann (2022) individually. The red bar represents the "Average: Rank-based Portfolio". Of course, there is a large amount of sampling variation, so among the many mimicking portfolios, some correlate more and some less with biodiversity news; but none performs as well as our economically-motivated measure.[24]

Panel (b) of Figure 7 shows the monthly out-of-sample return correlations for the portfolios built using the average biodiversity risk measure, and four mimicking portfolios built with the Fama-French Three Factors (Market, SMB, and HML), the Fama-French Five Factors (Market, SMB, HML, RMW, and CMA), and with all 212 characteristics and all 24 industries, each selected by LASSO to avoid over-fitting[25]. The portfolio built on the average biodiversity exposure measure has by far the highest correlation with innovations in the NYT-Biodiversity News Index.[26]

[23] Appendix Figure A.10 presents the portfolio weights of mimicking portfolios, constructed using Fama-French factors and 24 industry returns, estimated with OLS on the full sample. The results show almost no significant factor loadings.

[24] In Appendix A.4.3 we statistically compare the hedging performance of our biodiversity exposure measures, which are motivated a priori, with that of the 212 stock characteristics. The test explicitly takes into account the multiple testing problem associated with the 212 characteristics, which are not economically motivated—i.e., the fact that among the "characteristics zoo", we would expect some to be correlated with biodiversity risk well just by chance. To adjust for multiple testing, we use the method of Benjamini & Hochberg (1995). We find that the decent hedging performance of some of the 212 characteristics is indeed due to chance: none of them is significant after adjusting for the multiple testing problem.

[25] When the Lasso model fails to produce a prediction, for example, due to over-penalization or insufficient data, we impute the predicted value as zero, consistent with the model's behavior when it selects no features.

[26] Appendix Figure A.11 shows the hedge performance of a mimicking portfolio that includes Fama-French

Figure 7: Hedging Biodiversity Risk Using the Factor Zoo

(a) Correlation Distribution

(b) Hedging Performance

Note: Panel (a) shows the histogram of the out-of-sample correlations for mimicking portfolios with AR(1) innovations of the NYT-Biodiversity News Index using data from 2010 to 2023. The grey bars represent mimicking portfolios built using each of the 212 characteristics. The red bar is the "Average: Rank-based Portfolio". Panel (b) shows the dot plot of monthly out-of-sample return correlations for various hedge portfolios with AR(1) innovations of the NYT-Biodiversity News Index using data from 2010 to 2023. Each dot represents one correlation coefficient. The portfolios with blue labels are built based on the average of all biodiversity risk measures, using ranking-based and value-based approaches. The portfolios with red labels are the mimicking portfolios constructed with 24 industries, 212 characteristics, Fama-French Five Factors, and Fama-French Three Factors, and estimated each month using a five-year rolling window.

Overall, we find that the returns of portfolios sorted on various measures of biodiversity risk exposure covary positively with realizations of biodiversity news. These correlations are generally statistically significant and larger than correlations achievable using alternative characteristics. These findings suggest that our measures of both risk and exposure are reasonable, and that biodiversity risks are already reflected in equity valuations.

factors in addition to our biodiversity-risk-sorted portfolios. When needing to estimate the loading on these biodiversity-risk-sorted portfolios (and the Fama-French factors), the out-of-sample hedging performance declines significantly. Table 3 indicates that larger firms and those with higher market-to-book ratios face greater biodiversity risk, though this relationship was quite weak. Based on this prior, we also construct portfolios long in small, low market-to-book firms and short in their counterparts. Their near-zero or negative correlations with biodiversity risk (Appendix Figure A.11) suggest that biodiversity risk is not simply a proxy for size or value.

Hedging Biodiversity Risk vs. Climate Risk. To further explore the similarities and differences between climate and biodiversity risk, we also compute the monthly correlations between the returns of the biodiversity risk hedge portfolios and climate risk realizations. Specifically, column 2 of Table 5 reports the correlations between the various biodiversity hedge portfolio returns and innovations in the NYT-Climate News index introduced in Section 1. While our various biodiversity hedge portfolios perform well in terms of hedging biodiversity risk, they have, on average, close-to-zero correlations with realizations of news about climate risk. This is consistent with our finding of distinct realizations of aggregate climate and biodiversity risks, and the fact that climate and biodiversity risk exposures are not strongly correlated at the industry level.

3.1 Robustness and Additional Analyses.

We conduct a number of additional analyses to confirm the robustness of our baseline results and to extend them further.

While our baseline hedge portfolios are constructed using biodiversity risk exposures aggregated at the GICS 4-digit industry level, the underlying risk exposures based on 10-K, CDP, and biodiversity ETF holdings are, in principle, available at the firm level. To examine the impact of hedge asset granularity on our results, Appendix Figure A.12 presents the hedging performance of portfolios constructed with 72 GICS 6-digit industries and 175 GICS 8-digit industries. These portfolios are based on the average rankings across the 10-K, CDP, and holding-based measures. While the hedge portfolios continue to perform reasonably well with more finely disaggregated assets, their performance diminishes somewhat as more assets are included, highlighting the tradeoff between the noise in exposure estimation and the ability to capture true differences in exposures within industries.

We also assess the hedging performance of our procedure under alternative dictionaries used to filter the textual data for constructing the aggregate biodiversity news series, as described in footnote 8. The results, shown in Appendix Figure A.13, highlight that the hedging ability of our portfolios remains similar when the dictionary is changed, though they weaken somewhat when climate change words are included (because the news series will then be more informative about climate events and less about biodiversity events).

In an extension to our baseline results, we show in Appendix Figure A.14 that in the period 2000-2009, the hedging ability of the various portfolios is substantially weaker, and, in many cases, nonexistent. This finding is in line with the observation in other work that financial markets paid little attention to climate and nature-related risks prior to 2010 (see the discussions in Acharya et al. 2022, Alekseev et al. 2024). As a result, we would not have

expected news realizations to lead to price movements of exposed firms.

We also explore, in Appendix A.3, whether using the recent advances in large language modeling can help us make progress in distinguishing physical and transition biodiversity risk. As discussed above, this distinction is quite subtle and hard to detect using textual data: for example, when policymakers act to reduce physical risks, they often create transition risk. The Appendix uses LLM to try and disentangle the two types of risk both for the aggregate news series and the firm-level exposures. The results, while encouraging, are somewhat mixed, suggesting that these tools need to be further refined before being able to consistently distinguish physical and transition risks.

3.2 Survey Evidence on the Adequacy of Biodiversity Risk Pricing

While the prior section suggests that biodiversity risks are at least somewhat reflected in equity prices, it is less clear whether the current pricing is adequate to reflect the underlying risks. Answering this question is challenging, and requires taking a quantitative view on the nature of the risks and the ways they would affect the cash flows of different firms.

To provide some initial insights into this important question, we asked the respondents to our survey whether they believed that prices across a range of asset classes appropriately reflected biodiversity risks. Table 6 highlights that about half of all survey respondents believed that asset markets underpriced biodiversity risks across equity markets, commodity markets, sovereign debt markets, and real estate markets (in addition, about 35% of respondents had no particular views on the pricing of these risks, while fewer than 5% of respondents believed that these risks were overpriced). These responses are consistent across respondents from different institutions and locations. We also find that people who are worried about biodiversity are more likely to believe that asset markets have not yet priced biodiversity risks appropriately, while people with no concern think it is overpriced.

4 Conclusion

Ecosystem services play a fundamental role in the economy and risks stemming from biodiversity loss can affect firms through many channels. Yet, those risks can be difficult to quantify and study systematically. The goal of this paper is to introduce measures of aggregate biodiversity risk as well as measures of firms' and industries' exposures to these risks; to connect and validate these two; to study the pricing of biodiversity risks in financial markets; and to publicly release our biodiversity exposure measures at www.biodiversityrisk.org to facilitate more research on this important topic.

Table 6: Current pricing of biodiversity risks in asset markets

		Role			Location				Biodiversity Concern			
	Pooled	Academic Institution	Private Sector	Public Sector	North America	Europe	Asia	ROW	Very High	High	Low	No Concern
Stock Market (%)												
Not enough	48	43	53	61	45	53	60	69	71	53	30	6
Correct	17	23	11	15	18	17	13	23	11	26	33	23
Too much	3	3	5	3	5	1	2	0	2	2	8	29
No opinion	32	31	32	21	33	28	25	9	16	19	29	42
Commodity Market (%)												
Not enough	43	39	46	55	39	47	57	63	65	45	24	3
Correct	19	25	14	17	20	21	15	20	13	29	39	23
Too much	3	2	5	5	5	1	0	6	1	2	8	29
No opinion	35	35	35	22	36	30	28	11	20	24	29	45
Sovereign Debt Market (%)												
Not enough	43	39	44	58	41	48	50	60	65	45	29	3
Correct	14	20	10	8	16	13	12	9	6	23	33	19
Too much	2	2	2	4	2	1	2	6	0	2	3	26
No opinion	41	39	44	30	41	38	37	26	29	30	35	52
Real Estate Market(%)												
Not enough	46	42	48	61	45	51	53	54	66	51	32	3
Correct	16	22	12	9	17	15	13	20	10	23	32	29
Too much	2	1	3	3	2	2	0	3	0	1	5	26
No opinion	37	35	38	27	37	32	33	23	24	25	32	42

Note: Participants were asked: "To what extent do you think that physical or transition biodiversity risks are currently priced in the following asset markets?", where asset markets are either stock markets, real estate markets, commodity markets, or sovereign debt markets.

Given the complexity of biodiversity risk, our paper integrates multiple sources of information—including textual data, cross-sectional pricing information, and survey evidence—and develops methods to combine them into quantitative series that can be analyzed jointly. We view this work as a starting point for quantitative analyses of biodiversity risk. Following the research agenda described in Giglio et al. (2026), many extensions and refinements could be pursued, including the development of more advanced methods to measure biodiversity risks using additional data sources, such as earnings calls; spatial measures of biodiversity risk at the country and county level; an integrated study of the pricing of biodiversity risk across asset classes; and a more sophisticated distinction between the effects and pricing of transition and physical risks.

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A.1 Screenshots of Survey Flow

Figure A.1: Survey Introduction

We invite you to participate in a survey exploring your views on the importance of various biodiversity risks for investors and firms. This study aims to learn more about perceptions of biodiversity risk among academics and professionals. The survey is being conducted by Professor Stefano Giglio of Yale SOM, Professor Johannes Stroebel, Professor Theresa Kuchler and Xuran Zeng of NYU Stern.

If you agree to participate in this study, you will be asked to fill out a brief survey. Participation in this study will take about 5 minutes. There are no known risks associated with your participation in this research.

Since we are not collecting any personally identifiable information, the confidentiality of your responses will be maintained. Participation in this study is voluntary. You may refuse to participate or withdraw at any time without penalty. You have the right not to answer any questions you prefer not to answer.

If there is anything about the study or your participation that is unclear or that you do not understand, or if you have questions or wish to report a research-related problem, you may contact Xuran Zeng at xz4183@stern.nyu.edu.

For questions about your rights as a research participant, you may contact the Committee on Activities involving Human Subjects (UCAIHS), New York University, 665 Broadway, Suite 804, New York, New York 10012, at ask.humansubjects@nyu.edu or (212)998-4808. Please reference the study #(IRB-FY2023-7423) when contacting the IRB (UCAIHS).

Thank you very much for your participation.

Stefano Giglio, Theresa Kuchler, Johannes Stroebel and Xuran Zeng
Yale SOM & NYU Stern

○ I consent to participate in this study

Figure A.2: General Information

How is the institution at which you work best described?

- ○ Academic Institution
- ○ Public Sector
- ○ Private Sector

Where are you located?

- ○ North America
- ○ Europe
- ○ Asia
- ○ Rest of the World

What is your graduation year?

- ○ Before 2000
- ○ Between 2000 and 2009
- ○ After 2010

→

Figure A.3: Importance of Biodiversity Risk

How worried are you about the following aspects of biodiversity loss?

	Not at all worried	Not very worried	Somewhat worried	Very worried
Ecosystems Diversity Loss	○	○	○	○
Species Diversity Loss	○	○	○	○

Biodiversity risks for investors and firms are often divided into (i) physical risks coming from actual changes in biodiversity (e.g., reduced pollinators, freshwater scarcity) and (ii) transition risks coming from changes in the regulatory environment to combat biodiversity loss (e.g., the Clean Water Act). Please rate the financial materiality of these risks for corporations in the United States.

	Not at all important	Slightly important	Moderately important	Very important
Physical Biodiversity Risks	○	○	○	○
Transition Biodiversity Risks	○	○	○	○

Over what time horizon, if any, do you expect these biodiversity risks to materialize?

	Already today	1 to 5 years	5 to 30 years	More than 30 years	Never
Physical Biodiversity Risks	○	○	○	○	○
Transition Biodiversity Risks	○	○	○	○	○

→

Figure A.4: Importance of Biodiversity Risk (Industry Exposure)

Select the industries that you believe are most negatively affected by physical risks from biodiversity loss.

- [ ] Energy
- [ ] Pharmaceuticals, Biotech & Life Sciences
- [ ] Materials
- [ ] Banks and Diversified Financials
- [ ] Capital Goods
- [ ] Insurance
- [ ] Commercial & Professional Services
- [ ] IT and Communication Services
- [ ] Transportation
- [ ] Consumer Services and Retailing
- [ ] Automobiles, Consumer Durables and Household Products
- [ ] Utilities
- [ ] Food, Beverage & Tobacco
- [ ] Real Estate
- [ ] Health Care

Select the industries that you believe are most negatively affected by biodiversity transition risks.

- [ ] Energy
- [ ] Pharmaceuticals, Biotech & Life Sciences
- [ ] Materials
- [ ] Banks and Diversified Financials
- [ ] Capital Goods
- [ ] Insurance
- [ ] Commercial & Professional Services
- [ ] IT and Communication Services
- [ ] Transportation
- [ ] Consumer Services and Retailing
- [ ] Automobiles, Consumer Durables and Household Products
- [ ] Utilities
- [ ] Food, Beverage & Tobacco
- [ ] Real Estate
- [ ] Health Care

→

Figure A.5: Pricing of Biodiversity Risks

To what extent do you think that physical or transition biodiversity risks are currently priced int he following asset markets?

	Not enough	Correct	Too much	No opinion
Stock Markets	○	○	○	○
Commodity Markets	○	○	○	○
Sovereign Debt Markets	○	○	○	○
Real Estate Markets	○	○	○	○

Are there any particular ways in which biodiversity risks are important in your professional life?

→

A.2 Appendix Figures and Tables

Figure A.6: Industry Rankings with Biodiversity Measures

(a) 10K-Biodiversity-Count Score

(b) 10K-Biodiversity-Negative Score

Figure A.6: Industry Rankings with Biodiversity Measures (Cont.)

(c) 10K-Biodiversity-Regulation Score

(d) Holding-based Score

Figure A.6: Industry Rankings with Biodiversity Measures (Cont.)

(e) CDP-based Score

Note: Panels (a), (b), and (c) display industry rankings based on the 10-K Biodiversity Count Score, 10-K Biodiversity Negative Score, and 10-K Biodiversity Regulation Score, averaged from 2010 to 2023 and weighted by firm market capitalization. Panel (d) presents the Holding-based Score using data from Q4 2023. Panel (e) shows the CDP-based Score using data from 2023.

Figure A.7: Biodiversity Questions in the CDP Climate Change Questionnaire

(C15.4) Does your organization have activities located in or near to biodiversity- sensitive areas in the reporting year?

Change from last year

New question

Connection to other frameworks

SDG

Goal 15: Life on Land

Response options

Select one of the following options:

- Yes
- No
- Not assessed

(C15.4a) Provide details of your organization's activities in the reporting year located in or near to biodiversity -sensitive areas.

Question dependencies

This question only appears if you select "Yes" in C15.4.

Change from last year

New question

Connection to other frameworks

SDG

Goal 15: Life on Land

Response options

Please complete the following table. *Column/row appearance is dependent on selections in this or other questions.

1	2	3	4	5
Classification of biodiversity -sensitive area	Country/area	Name of the biodiversity-sensitive area	Proximity	Briefly describe your organization's activities in the reporting year located in or near to the selected area
Select from: • Natura 2000 network of protected areas • UNESCO World Heritage site • Key Biodiversity Area (KBAs) • Other biodiversity sensitive area, please specify	Select from: [List of countries/areas]	Text field [maximum 500 characters]	Select from: • Overlap • Adjacent • Up to 5 km • Up to 10 km • Up to 25 km • Up to 50 km • Up to 70 km • Data not available	Text field [maximum 2,500 characters]

6	7	8
Indicate whether any of your organization's activities located in or near to the selected area could negatively affect biodiversity	Mitigation measures implemented within the selected area*	Explain how your organization's activities located in or near to the selected area could negatively affect biodiversity, how this was assessed, and describe any mitigation measures implemented*
Select from: • Yes, but mitigation measures have been implemented • Yes, and no mitigation measures have been implemented • No • Not assessed	Select all that apply: • Site selection • Project design • Scheduling • Physical controls • Operational controls • Abatement controls • Restoration • Biodiversity offsets • Other, please specify	Text field [maximum 3,000 characters]

Note: Figure shows the questions on biodiversity in the CDP Climate Change Questionnaire.

Figure A.8: Word Cloud: Biodiversity Vocabulary by Sector

(a) Energy Sector

(b) Utilities Sector

(c) Food, Beverage, & Tobacco Sector

(d) Materials Sector

(e) Pharmaceutical, Biotechnology, & Life Sciences Sector

(f) Real Estate Sector

Note: Word cloud summary of vocabulary from biodiversity sentences mentioned in firms' 10-K statements. Term sizes are proportional to their frequency in the corpus.

Figure A.9: Industry and Subindustry Rankings with Biodiversity Measures

Note: The figure displays the ranking of industry biodiversity risk exposure using the 10-K Biodiversity Count Score, sorted by both 4-digit and 6-digit GICS industry codes. This exposure is measured by the proportion of 10-K statements that mention biodiversity in the corresponding sector, averaged from 2010 to 2023. We keep the 4-digit industries only when at least 1% of the firms have a mention and drop the rest, including Automobiles & Components, Banks, Communication Services, Diversified Financials, Food & Staples Retailing, Health Care Equipment & Services, Insurance, Media & Entertainment, Pharmaceutical, Biotechnology & Equipment, Semiconductors & Semiconductor Equipment, Software & Services, and Technology, Hardware & Equipment.

Figure A.10: Mimicking Portfolios Weights

(a) Fama-French Three Factors

(b) Fama-French Five Factors

(c) Industry Returns

Note: Panel (a) and (b) report the portfolio weights of mimicking portfolios constructed with the Fama-French Three Factors and Fama-French Five Factors estimated on the full sample of 2010 to 2023. Panel (c) reports the portfolio weights of mimicking portfolios constructed with industry returns. The standard errors are Newey-West adjusted and the band shows 95% confidence interval.

Figure A.11: Biodiversity Hedge Performance of Characteristics-Adjusted Portfolios

Note: Dot plot of monthly return correlations for various biodiversity hedge portfolios and mimicking portfolios with AR(1) innovations of NYT-Biodiversity News Index using data from 2010 to 2023. Each dot represents one correlation coefficient. Blue-labeled portfolios are built based on the ranking across the 10K-, CDP-, survey- and holding-based exposures. Red-labeled portfolios are the mimicking portfolios constructed with the average biodiversity risk exposure and Fama-French factors, estimated each month using a five-year rolling window. Green-labeled portfolios are constructed based on the prior that small and value firms are associated with low exposure to biodiversity risk.

Figure A.12: Biodiversity Hedge Performance of Various Granular Portfolios

Note: Dot plot of monthly return correlations for various biodiversity hedge portfolios based on the average ranking across the 10K-, CDP-, and holding-based exposures with AR(1) innovations of NYT-Biodiversity News Index using data from 2010 to 2023. Each row corresponds to a different level of aggregation used to measure industry-level biodiversity risk exposure. Each dot represents one correlation coefficient.

Figure A.13: Biodiversity Hedge Performance with Alternative Hedge Targets

Note: Dot plot of monthly return correlations for various biodiversity hedge portfolios with AR(1) innovations of NYT-Biodiversity News Index, as well as alternative biodiversity news series built with different dictionaries to filter the textual data, using data from 2010 to 2023. "Baseline Biodiversity Dictionary" is constructed using all terms in the Biodiversity Dictionary except "climate change"; "Biodiversity Excluding Climate Change Dictionary" includes terms in the Biodiversity Dictionary that are not in the Climate Change Dictionary; "Biodiversity Excluding Climate Dictionary" uses terms in the Biodiversity Dictionary that are not in the Climate Dictionary; and "Full Biodiversity Dictionary" includes all terms in the Biodiversity Dictionary; The Biodiversity Dictionary (Appendix Table A.3) lists the top 100 words closest to "biodiversity"; the Climate Dictionary (Appendix Table A.4) lists those closest to "climate"; and the Climate Change Dictionary (Appendix Table A.5) lists those closest to "climate change".

Figure A.14: Biodiversity Hedge Performance of Various Portfolios Before 2010

Note: Dot plot of monthly return correlations for various biodiversity hedge portfolios with AR(1) innovations of NYT-Biodiversity News Index using data from 2000 to 2009. Each dot represents one correlation coefficient.

Table A.1: Composition of Survey Respondents

		Role			Location				Biodiversity Concern			
	Pooled	Academic Institution	Private Sector	Public Sector	North America	Europe	Asia	ROW	Very High	High	Low	No Concern
Role (%)												
Academic Institution	48	100	0	0	46	53	52	43	43	56	53	52
Private Sector	34	0	100	0	42	15	35	26	39	23	36	35
Public Sector	18	0	0	100	13	31	13	31	18	20	11	13
Location (%)												
North America	62	59	76	43	100	0	0	0	58	60	71	70
Europe	23	26	10	41	0	100	0	0	23	27	15	13
Asia	9	10	10	7	0	0	100	0	11	9	11	13
Rest of the World	5	5	4	9	0	0	0	100	9	4	3	3
Ecosystem Diversity Loss Concern (%)												
Not at all worried	8	9	9	5	9	6	9	6	1	3	9	100
Not very worried	24	26	23	20	26	20	26	14	6	27	91	0
Somewhat worried	35	37	28	40	34	36	38	26	19	69	0	0
Very worried	34	28	40	35	31	38	28	54	73	0	0	0
Species Diversity Loss Concern (%)												
Not at all worried	7	7	6	11	8	6	7	9	1	1	9	100
Not very worried	20	22	19	18	22	19	19	11	8	17	91	0
Somewhat worried	42	46	34	46	40	50	36	40	26	82	0	0
Very worried	30	25	41	25	30	25	38	40	66	0	0	0
Graduation Year (%)												
Before 2000	30	29	35	24	33	27	13	35	30	32	20	32
Between 2000 and 2009	30	28	32	30	27	35	33	29	30	26	41	39
After 2010	40	44	33	46	40	38	53	35	40	41	39	29

Note: The percentage breakdowns in the table are to be read in columns within blocks. For example, the share of finance academics in North America is 46%, while the share of North American respondents among finance academics is 59%. The total number of respondents is 668. The table shows the distribution among respondents who answered the question of interest. The level of Biodiversity Concern shown in the last columns column is determined by the maximum value between Ecosystem Diversity Loss Concern and Species Diversity Loss Concern.

Table A.2: Example Answers From Open Text Survey Question

Role	Answer
Private Sector	I invest in early-stage climate tech companies, so I am constantly thinking about biodiversity risks and companies that are addressing those risks.
Private Sector	I co-run an investment fund in farmland and timberland, which are directly affected by these risks.
Private Sector	loss of key ecosystem services for agriculture and manufacturing.
Private Sector	Assessing project risks properly given biodiversity risks bring greater uncertainties that we have less foresight in factoring them into the overall viability of infrastructure projects.
Private Sector	I cover part of the energy sector so the physical risk is something we look at.
Private Sector	Yes, as a real estate investor.
Private Sector	Yes as a ESG stock analyst we are seeing an increased focus on biodiversity risk and policy action
Private Sector	More demand for consulting services on the matter
Private Sector	There are insufficient risk disclosures by borrowers and a lack of standard disclosures from which capital markets can appropriately assess and price risk.
Private Sector	Yes I work in Climate Risk for A Bank and biodiversity is something we are looking at now. While biodiversity risk is important to manage it should be done in consideration of economic challenges such as inflation & recession risk and we are in favor or a just transition especially as we operate in developing markets
Private Sector	Yes, companies are now considering biodiversity risks and asking for my expertise in this field more which is very encouraging, while helping companies change their practices with nature.
Private Sector	Regulatory risks related to biodiversity are chief drivers of long-term uncertainty in the energy markets in which I work.
Private Sector	There are insufficient risk disclosures by borrowers and a lack of standard disclosures from which capital markets can appropriately assess and price risk.
Private Sector	As working in the buy side, we are focusing more on impact investment to address ESG issues, including to moderate biodiversity risk
Private Sector	It definitely informs the kind of companies I negatively screen. We don't have an active biodiversity risk strategy; but I tend to negatively view companies that will cause harm to our environment form a long-term business sustainability perspective (as a VC)

Note: Participants were asked: Are there any particular ways in which biodiversity risks are important in your professional life?

Table A.2: Example Answers From Open Text Survey Question (Cont.)

Role	Answer
Private Sector	Risk gets re-priced when recognition of those risks becomes generally understood. This raises the cost of capital for businesses which tends to be negative for capital assets in general, especially if its a "shock." This, combined with a re-pricing of negative externalities associated with activities leading to biodiversity loss creates uncertainty that investors and companies eventually need to confront. The confrontation can result in innovation or decline or both. All of this makes investment decisions much more difficult.
Private Sector	I am a hedge fund investor and find that companies well suited to address changes are overpriced, especially global stocks. The point is that there are private sector companies that I may not know about.
Public Sector	I live in a tropical country with an economy that still heavily dominated by commodities export the sustainability of biodiversity in the environment becomes very important.
Public Sector	The influence of transition related measures such as tariffs, offsets and financial market instruments leading to suboptimal conservation behavior.
Public Sector	Biodiversity risks may affect the economy and thereby price stability.
Public Sector	Biodiversity risks are a serious threaten to financial stability and the resilience of financial companies. As such, they have a strong impact on my professional life.
Public Sector	Potential regulatory developments.
Public Sector	Looking for ways to modernize economic thinking that humans are part of nature and human capital is a component of natural capital. Good, robust natural capital depends on biodiversity.
Public Sector	Absolutely. Loss of biodiversity and area for animals animals to move closer to cities, causing a great chance for diseases to spread to humans, which may cause another pandemic. There's dozens of other examples I could also list.
Academic Institution	Impacts the food and bevearge industry with whom I work closely.
Academic Institution	Yes, research on the link between human rights and climate - biodiversity protection.
Academic Institution	As a researcher, it is an imperative that scholars support corporates and other organizations in mitigation and adaptation to limit biodiversity loss risk.
Academic Institution	it is a main issue of assessing the value of natural capital.
Academic Institution	I think biodiversity risks are important for non-financial aspects of utility such as tourism and leisure. They may combine with other changes underway to create a worse planet. I am not sure if they would be paramount to financial economics, other than perhaps via impact on health, pharma, medicine, etc., where biodiversity serves a useful purpose as an essential input to innovative solutions to problems pertinent to common man (who is not much in finance!).

Note: Participants were asked: Are there any particular ways in which biodiversity risks are important in your professional life?

Table A.3: List of Top 100 Words Similar to 'biodiversity'

Word	Distance	Word	Distance	Word	Distance	Word	Distance
bio_diversity	0.7953	coral_reefs	0.6151	rainforest	0.5661	wetlands	0.5492
Biodiversity	0.7261	aquatic_ecosystems	0.6132	overexploitation	0.5657	Unep	0.5489
biodiversity_conservation	0.7226	marine_ecosystem	0.6078	insect_pollinators	0.5652	Biological_Diversity_CBD	0.5473
ecosystems	0.7113	tropical_rainforests	0.6058	biosphere_reserves	0.5650	extinctions	0.5464
marine_biodiversity	0.7011	species	0.6046	transboundary	0.5641	amphibian_populations	0.5461
deforestation	0.6494	species_extinctions	0.6029	aquatic_habitats	0.5624	ecological_degradation	0.5459
ecological	0.6492	biodiverse	0.5995	wildlife	0.5618	habitat_fragmentation	0.5451
ecology	0.6430	combating_desertification	0.5959	wetland_habitats	0.5618	wetland_ecosystem	0.5424
habitats	0.6428	seagrasses	0.5938	sea_turtle_populations	0.5585	amphibian_species	0.5424
fauna	0.6407	desertification	0.5936	coral_reef_ecosystems	0.5581	tropical_rainforest	0.5423
conserving_biodiversity	0.6394	avifauna	0.5909	coral_reef_ecosystem	0.5578	IPBES	0.5402
marine_ecosystems	0.6389	tropical_forest	0.5890	IUCN	0.5573	migratory_bird_populations	0.5401
freshwater_ecosystems	0.6365	ocean_ecosystems	0.5878	coral_ecosystems	0.5573	genetic_diversity	0.5393
forest_ecosystems	0.6356	conservation	0.5875	grassland_birds	0.5562	ecotourism	0.5383
tropical_forests	0.6354	tropical_deforestation	0.5841	wetland	0.5546	seagrass_meadows	0.5382
wetland_ecosystems	0.6281	soil_fertility	0.5795	wildlife_habitat	0.5544	pollinating_insects	0.5380
flora	0.6271	forests	0.5768	mangrove_forests	0.5537	peat_lands	0.5378
conserve_biodiversity	0.6270	climate_change	0.5760	environmental_degradation	0.5535	Biodiversity_Strategy	0.5374
biodiversity_hotspot	0.6254	birdlife	0.5758	endemism	0.5529	Wet_Tropics	0.5362
rainforests	0.6243	drylands	0.5741	riparian_zones	0.5524	Coral_Triangle	0.5361
coastal_ecosystems	0.6199	biosphere	0.5725	genebanks	0.5505	peatland	0.5359
biodiversity_hotspots	0.6170	aquatic_ecosystem	0.5722	Protected_Areas	0.5501	fragile_ecosystems	0.5354
habitat	0.6166	native_flora	0.5722	delicate_ecosystems	0.5499	freshwater_habitats	0.5353
carbon_sinks	0.6157	degraded_ecosystems	0.5678	Desertification	0.5496	Biodiversity_Conservation	0.5346
wildlife_habitats	0.6155	terrestrial_ecosystems	0.5668	soil_erosion	0.5494	fisheries	0.5333

Note: This table shows the list of top 100 words based on their cosine similarity to "biodiversity" in Google's word2vec implementation. IUCN: International Union for Conservation of Nature; Unep: United Nations Environment Programme; IPBES: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services; Biological_Diversity_CBD: The Convention on Biological Diversity (CBD). Terms in red are the common terms in Appendix Table A.3, Appendix Table A.4, and Appendix Table A.5, i.e., terms related to both biodiversity and climate/climate change.

Table A.4: List of Top 100 Words Similar to 'climate'

Word	Distance	Word	Distance	Word	Distance	Word	Distance
climate_change	0.6570	Bjørn_Lomborg	0.4524	Stefan_Rahmstorf	0.4293	warmer_wetter	0.4174
Climate	0.6231	greenhouse_gases	0.4510	CO2_concentrations	0.4278	radiative_forcing	0.4171
climates	0.6195	wetter_winters	0.4507	hydrologic_cycle	0.4278	subterranean_swelter	0.4171
global_warming	0.6047	greenhouse_gas_concentrations	0.4495	El_Nino_La_Nina	0.4268	Climategate_scandal	0.4166
environment	0.6010	anthropogenic_warming	0.4491	Ice_Ages	0.4267	biodiversity	0.4157
climatic	0.5555	microclimate	0.4479	paleoclimatologist	0.4263	Bjorn_Lomborg	0.4149
climatic_conditions	0.5207	hotter_summers	0.4465	balmier	0.4259	paleoclimatology	0.4145
Global_warming	0.5049	Global_Warming	0.4444	warmists	0.4237	atmospheric_circulation	0.4143
Climate_Change	0.4956	global_warming_alarmists	0.4444	ozone_depletion	0.4236	reducing_carbon_emissions	0.4133
anthropogenic_climate	0.4938	climatic_variations	0.4434	paleoclimate	0.4233	coastal_ecosystems	0.4132
weather	0.4833	Nielsen_Gammon	0.4431	conditions	0.4230	planetary_warming	0.4109
CLIMATE	0.4830	greenhouse_gas	0.4376	Veerabhadran_Ramanathan	0.4230	Eileen_Claussen_president	0.4106
hotter_drier	0.4771	climate_modelers	0.4374	climatology	0.4221	warming	0.4102
solar_irradiance	0.4764	carbon_emissions	0.4368	ecosystems	0.4213	atmospheric_CO2_concentrations	0.4098
greenhouse_warming	0.4683	biogeochemical_cycles	0.4354	thermohaline_circulation	0.4208	emitting_greenhouse_gases	0.4097
warmings	0.4666	climatologically	0.4351	Polar_Regions	0.4204	atmospheric	0.4097
oceanic_circulation	0.4655	Climatologist	0.4344	warmer_drier	0.4201	cooler_wetter_weather	0.4088
climatically	0.4654	ozone_layer_depletion	0.4343	Pielke	0.4200	Roger_Pielke_Jr.	0.4087
climatological	0.4626	anthropogenic	0.4329	Warming	0.4198	atmospheric_CO2	0.4084
forcings	0.4619	El_Nino_periodic	0.4316	carbon_emission	0.4196	manmade_global_warming	0.4079
atmosphere	0.4598	climatechange	0.4311	Copenhagen_Climate	0.4189	anthropogenic_emissions	0.4078
climatic_variability	0.4595	Schellnhuber	0.4299	cooler_wetter	0.4184	atmospheric_carbon_dioxide	0.4075
economic	0.4587	greenhouse_gas_emissions	0.4296	anthropogenic_global_warming	0.4183	emissions	0.4071
Climatic	0.4576	biosphere	0.4295	curbing_carbon_emissions	0.4175	warmer	0.4062
colder_wetter	0.4525	aridity	0.4294	climatologists	0.4175	clime	0.4054

Note: This table shows the list of top 100 words based on their cosine similarity to "Climate" in Google's word2vec implementation. Terms in red are the common terms in Appendix Table A.3, Appendix Table A.4, and Appendix Table A.5, i.e., terms related to both biodiversity and climate/climate change.

Table A.5: List of Top 100 Words Similar to 'climate change'

Word	Distance	Word	Distance	Word	Distance	Word	Distance
global_warming	0.8896	climatechange	0.5673	species_extinctions	0.5250	melting_polar	0.5056
Climate_Change	0.7148	reduce_carbon_emissions	0.5671	emission_reduction	0.5242	decarbonisation	0.5054
Climate	0.6954	curbing_greenhouse_gases	0.5631	Hans_Verolme	0.5197	coastal_erosion	0.5052
Global_warming	0.6611	Climate_Change_IPCC	0.5620	greenhouse_gas_concentrations	0.5197	climatic	0.5048
climate	0.6570	melting_icecaps	0.5577	Schellnhuber	0.5180	IAASTD	0.5048
greenhouse_gas_emissions	0.6449	curbing_carbon_emissions	0.5519	carbon	0.5167	melting_glaciers	0.5041
greenhouse_gases	0.6433	Bjørn_Lomborg	0.5517	Worldwatch	0.5160	CLIMATE	0.5034
carbon_emissions	0.6395	greenhouse_warming	0.5502	CO2_emissions	0.5158	halting_deforestation	0.5030
Global_Warming	0.6282	greenhouse_gas_emission	0.5442	Steven_Guilbeault	0.5149	greenhouse_gas_GHG_emissions	0.5025
reducing_carbon_emissions	0.6227	ocean_acidification	0.5441	climatic_variability	0.5148	GHGs	0.5024
greenhouse_emissions	0.6146	combatting_global_warming	0.5438	GHG_emissions	0.5144	environmentalism	0.5019
combating_global_warming	0.6045	Al_Gore_Inconvenient_Truth	0.5437	Bjorn_Lomborg	0.5142	Eaarth	0.5018
greenhouse_gasses	0.6019	Lomborg	0.5407	greenhouses_gases	0.5140	conserving_biodiversity	0.5007
tropical_deforestation	0.5970	manmade_global_warming	0.5397	environmental	0.5124	greenhouse_gas_emission_reductions	0.5002
anthropogenic_climate	0.5918	emissions	0.5379	Climate_Change_Secretariat	0.5122	reduce_greenhouse_gas	0.5001
deforestation	0.5914	greenhouse_gas_emitters	0.5372	ozone_depletion	0.5112	fossil_fuels	0.4997
greenhouse_gas	0.5857	anthropogenic_global_warming	0.5369	Environment_Programme_Unep	0.5110	UNFCCC_Executive	0.4996
carbon_emission	0.5765	environmental_degradation	0.5343	UNFCC	0.5107	pollution	0.4992
biodiversity	0.5760	Unep	0.5338	Di_Aping	0.5098	greenhouse_gases_GHGs	0.4990
greenhouse_emission	0.5738	global_warming_alarmists	0.5332	anthropogenic	0.5096	atmospheric_carbon_dioxide	0.4984
desertification	0.5708	carbon_sinks	0.5326	reducing_greenhouse_gas	0.5093	glacial_melting	0.4984
carbon_dioxide_emissions	0.5688	planetary_warming	0.5299	carbon_sequestration	0.5085	TEEB	0.4982
Climate_Change_UNFCC	0.5686	floods_droughts	0.5288	Pachauri	0.5080	Ocean_Acidification	0.4982
resource_depletion	0.5680	Copenhagen_Climate	0.5263	GLOBAL_warming	0.5069	COP	0.4980
ozone_layer_depletion	0.5676	Climatic_Change	0.5258	G8_+5	0.5064	warmists	0.4974

Note: This table shows the list of top 100 words based on their cosine similarity to "Climate Change" in Google's word2vec implementation. UNFCC: United Nations Framework Convention on Climate Change; IPCC: Intergovernmental Panel on Climate Change. Terms in red are the common terms in Appendix Table A.3, Appendix Table A.4, and Appendix Table A.5, i.e., terms related to both biodiversity and climate/climate change.

Table A.6: Correlation Across Measures of Aggregate Risk - Alternative News Indices

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Biodiversity Risk Measures									
(1) NYT-Biodiversity News (Baseline)	1.00								
(2) NYT-Biodiversity News (All 100 terms)	0.73	1.00							
(3) NYT-Biodiversity News (Excluding Climate Dictionary)	0.98	0.73	1.00						
(4) NYT-Biodiversity News (Excluding CC Dictionary)	0.97	0.69	0.96	1.00					
Climate Risk Measures									
(5) NYT-Climate News	0.43	0.85	0.43	0.38	1.00				
(6) Faccini et al (2023): Climate Policy	0.20	0.46	0.18	0.16	0.50	1.00			
(7) Faccini et al (2023): Internat. Summit	−0.11	−0.17	−0.12	−0.09	−0.14	0.11	1.00		
(8) Faccini et al (2023): Global Warming	0.10	0.44	0.07	0.06	0.51	0.76	0.21	1.00	
(9) Faccini et al (2023): Natural Disaster	0.21	0.49	0.19	0.15	0.64	0.41	−0.06	0.41	1.00

Note: Pairwise monthly correlation across biodiversity and climate risk measures. NYT-Biodiversity News and NYT-Climate News use data from January 2010 to December 2023, while Faccini et al (2023) indices span January 2010 to June 2023. (1) NYT-Biodiversity News (Baseline) is constructed using all terms in the Biodiversity Dictionary except"climate change"; (2) NYT-Biodiversity News (All 100 Terms) includes all terms in the Biodiversity Dictionary; (3) NYT-Biodiversity News (Excluding Climate Dictionary) uses terms in the Biodiversity Dictionary that are not in the Climate Dictionary; (4) NYT-Biodiversity News (Excluding Climate Change Dictionary) includes terms in the Biodiversity Dictionary that are not in the Climate Change Dictionary. The Biodiversity Dictionary (Appendix Table A.3) lists the top 100 words closest to "biodiversity"; the Climate Dictionary (Appendix Table A.4) lists those closest to "climate"; and the Climate Change Dictionary (Appendix Table A.5) lists those closest to "climate change".

Table A.7: BERT classification examples: NYT

Panel A: Negative Sentences	
biodiversity	It is hard to believe that the Trump administration and the current Senate will be any more enthusiastic about preserving **biodiversity** than the Senate was then.
deforestation	Environmental problems remain, including overfishing and the erosion and **deforestation** left from earlier eras.
habitat	The antelope's numbers, once in the millions, have been severely depleted by illegal hunting, **habitat** loss and competition for food.
marine	There is concern, too, about the effect of broken-down plastic on **marine** life.
species	Even so, in August, the United States Fish and **Wildlife** Service withdrew its proposal to list the animal as a "threatened" species under the Endangered **Species** Act.
Panel B: Positive Sentences	
biodiversity	These organic seed sellers share a passion for the unusual and a mission to preserve **biodiversity**.
species	It highlights where endangered wild lands are being preserved, threatened **species** are being protected, historical wrongs are being acknowledged and fragile communities are being bolstered.
desertification	In the mid-2000s, African leaders envisioned creating a huge swath of green that could help combat **desertification** and land degradation.
habitat	In cities, trees cool hot streets, absorb pollution, improve air quality, limit storm water runoff, prevent erosion, enhance the physical and mental health of human beings, and provide desperately needed **habitat** for wildlife.

Note: Sentences classified as positive are assigned a score of 1, and sentences classified as negative are assigned a score of -1.

Table A.8: BERT classification examples: 10-K

Panel A: Negative Sentences	
Materials	Long-term, higher average global temperatures could result in induced charges in natural resources, growing seasons, precipitation patterns, weather patterns, species distributions, water availability, sea levels, and **biodiversity**.
Energy	If our access to materials under **biodiversity** access agreements or other arrangements is reduced or terminates, it could harm our internal and our collaborative research and development efforts.
Consumer Services	These risks include the increased public focus, including by governmental and nongovernmental organizations, on these and other environmental sustainability matters, such as packaging and waste, animal health and welfare, **deforestation** and land use.
Pharma., Biotech., & Life Sc.	The natural oils and fats route can lead to concerns of **deforestation** due to the rapid expansion of palm oil plantations to meet growing demand.
Energy	If one of our LNG terminals or pipelines adversely affects a protected species or its **habitat**, we may be required to develop and follow a plan to avoid those impacts.
Panel B: Positive Sentences	
Semi. & Equip.	We leverage our expertise to develop new solutions to help restore natural resources, regenerate the quality of our **biosphere** and reduce carbon emissions.
Pharma., Biotech., & Life Sc.	We believe that growth of hemp could significantly reduce **deforestation** by providing the same products that trees are able to supply.
Materials	The Company follows Sustainable Forestry Initiative ("SFI") Standards that promote sustainable forest management in North America through the use of core principles, objectives, performance measures and indicators to protect water quality, **biodiversity**, wildlife habitat, species at risk, and forests which have exceptional conservation value.
Real Estate	Such forest practices include planting 300 to 600 seedlings on each acre, thinning **forest** stands to give remaining trees more room to grow, pruning selected trees to produce knot-free wood, fertilizing stands to supplement natural nutrient levels, and harvesting at sustainable rates-approximately 2 percent of our forestlands each year in the West and 3 percent in the South where the growing cycle is faster.
Materials	Our efforts to advance sustainable **forest** management and restore **forest** landscapes are an important lever for mitigating climate change through carbon storage in forests.

Note: Sentences classified as positive are assigned a score of 1, and sentences classified as negative are assigned a score of -1. Panel A shows the sentences that are classified as negative by BERT, while Panel B presents the positive sentences.

Table A.8: BERT classification examples: 10-K (Cont.)

Panel C: Neutral Sentences	
Food, Bev. & Tobacco	The Company continues to own the property and continues to conduct its long-term water dispersement program and **wildlife** management programs.
Energy	Fish and Wildlife Service (the "FWS") announced a series of changes to the rules implementing the ESA, including revisions to the regulations governing interagency cooperation, listing species and delisting critical **habitat**, and prohibitions related to threatened wildlife and plants.
Materials	The U.S. EPA alleges the original **wetland** area has been partially filed by various waste handling and disposal activities which started as early as the 1940's.
Retailing	In fiscal 2018, we published an updated wood sourcing policy to ensure that all wood products sold in our stores originate from well-managed, non-endangered **forests** and committed to achieve 100 percent Forest Stewardship Council (FSC) certification for all wood products sourced from identified regions at risk by 2020.
Capital Goods	If endangered **species** or their **habitats** are identified, ESA requirements for protection, mitigation or avoidance apply.
Panel D: Transition Sentences	
Energy	A critical **habitat** or suitable habitat designation could result in further material **restrictions** to federal land use and may materially delay or prohibit access to protected areas for natural gas and oil development.
Consum. Durables & Apparel	Recent regulatory action involving the listing of a certain **species** of gopher as 'threatened' under the federal Endangered Species Act may adversely affect this project, for example by imposing new **restrictions** and requirements on our activities there and possibly delaying, halting or limiting, our development activities.
Materials	In addition, future domestic or foreign legislation or **regulation**, litigation advanced by Aboriginal groups and litigation concerning the use of timberlands, forest management practices, the protection of endangered **species**, the promotion of **forest biodiversity** and the response to and prevention of catastrophic wildfires could also affect timber supplies.
Real Estate	Federal, state and local **laws** and regulations, as well as those of other countries, which are intended to protect threatened and endangered **species**, as well as waterways and wetlands, limit and may prevent timber harvesting, road building and other activities on our timberlands.

Note: Panel C shows the neutral sentences identified by BERT. Panel D presents examples of sentences marked as biodiversity transition risk sentences.

Table A.9: Confusion Matrix for Text-based Measures

Panel (A) NYT-Sentiment Classification

	Machine Classification				
Human Classification	Negative	Neutral	Positive	Total	Recall
Negative	16	3	0	19	84.21%
Neutral	5	50	1	56	89.29%
Positive	0	13	12	25	48.00%
Total	21	66	13	100	
Precision	76.19%	75.76%	92.31%		

Panel (B) 10K-Sentiment Classification

	Machine Classification				
Human Classification	Negative	Neutral	Positive	Total	Recall
Negative	10	7	0	17	58.82%
Neutral	1	78	1	80	97.50%
Positive	0	1	2	3	66.67%
Total	11	86	3	100	
Precision	90.91%	90.70%	66.67%		

Panel (C) 10K-Policy Classification

	Machine Classification			
Human Classification	Policy-related	Policy-unrelated	Total	Recall
Policy-related	39	7	46	84.78%
Policy-unrelated	8	46	54	85.19%
Total	47	53	100	
Precision	82.98%	86.79%		

Note: This table presents confusion matrices for manually classified biodiversity-related sentences from NYT articles and 10-K filings. Each panel corresponds to a different classification task: (i) sentiment classification for the NYT-Biodiversity News Index, (ii) negative sentiment classification for the 10K-Negative Score, and (iii) policy relevance classification for the 10K-Regulation Score. Each matrix compares human-labeled classifications with model predictions based on 100 sampled sentences. Rows represent actual classifications, while columns represent predicted classifications.

Table A.10: Misclassification examples

Source	Code Label	Manual Label	Sentence
NYT	Neutral	Positive	The money would go to programs like protecting ocean and air quality and wildlife and improving parks.
NYT	Neutral	Negative	More than three quarters of oceanic shark and ray species are now threatened with extinction, jeopardizing marine ecosystems and the food security of people in many nations.
NYT	Positive	Neutral	While per-unit prices are among the highest in the nation, stringent energy conservation measures have helped keep monthly bills $20 lower than the United States average, since Californian homes use almost 40 percent less electricity than the typical American household.
10-K	Neutral	Negative	Such laws require that we take steps to, among other things, maintain air and water quality standards, protect threatened, endangered and other species of wildlife and vegetation, preserve certain cultural resources, and reclaim processing sites and package potentially flammable materials in appropriate ways.
10-K	Related to policy	Unrelated to policy	The HH-65 is a medium-range recovery helicopter used to perform search and rescue, law enforcement, military readiness, and marine environmental protection missions.
10-K	Unrelated to policy	Related to policy	Fish and Wildlife Service may designate critical habitat and suitable habitat areas that it believes are necessary for survival of threatened or endangered species.

Note: This table presents misclassified examples from NYT and 10-K statements.

Table A.11: 100 Sentences from NYT

Code Label	Manual Label	Sentence
Positive	Positive	A new NASA program is helping researchers more accurately calculate how much planet-warming carbon protected areas are storing.
Positive	Positive	Already some 200 low impact projects in the United States have been approved or are pending , and across Europe there may be nearly at old mills.Simply ripping out obsolete structures can have a big effect, too, restoring rivers to a free-flowing state with tremendous ecological and recreational benefits.
Positive	Positive	But it also highlighted that conservation projects could be successful, as with wetland species, like mallards and blue-winged teals, which saw a 37 percent bump in population since 1968.
Positive	Positive	Compost is known to farmers as "black gold" because it helps plants take root and prevents soil erosion.
Positive	Positive	In the aftermath, a movement to save the Amazon gained impetus.Brazilś leaders now saw merit in putting the brakes on deforestation.
Positive	Positive	In the first five months of the year, unit sales of a wide range of conservation products were up strongly, in some cases double sales of a year ago, Home Depot said.
Positive	Positive	Larger forests around the world have already been enlisted as carbon storehouses, through programs like the United Nations initiative for Reducing Emissions From Deforestation and Forest Degradation, or REDD, that encourage forest conservation worldwide in exchange for credits that can be sold on the global carbon markets.
Positive	Positive	People came to feel that it was deeply wrong, perhaps evil, to engage in nuclear war, and are coming to an awareness that it is deeply wrong, perhaps evil, to destroy our habitat and create a legacy of suffering for our children and grandchildren.
Positive	Positive	That change is comparable, the authors wrote, to a human becoming the size of a Rhesus monkey.“The evolutionary rate they estimated the elephants to shrink (adapt) is remarkable,” wrote Mirte Bosse, a conservation genomics researcher at Wageningen University in the Netherlands, who was not involved in the research.
Positive	Positive	The meadowlands has this incredible biodiversity with real beauty, believe it or not.
Positive	Positive	The national bird, the kiwi, has hatched eggs in the wild in the Wellington area for the first time in living memory, thanks to a multiyear conservation effort.
Positive	Positive	Today, it draws roughly two million visitors yearly as a leading center of conservation and research. The bay itself has also been revived.

Note: This table presents 100 random examples from NYT with machine classification and human classification.

Table A.11: 100 Sentences from NYT (Cont.)

Code Label	Manual Label	Sentence
Positive	Neutral	While per-unit prices are among the highest in the nation, stringent energy conservation measures have helped keep monthly bills $20 lower than the United States average, since Californian homes use almost 40 percent less electricity than the typical American household.
Neutral	Positive	Another $180 million will go toward reducing pollution from working farms and managing forests to remove old and dead trees to make room for young trees that absorb more nutrients from rain and snow melt that run into the reservoirs.
Neutral	Positive	But their numbers in Russia have risen from just 30 in 2007 to nearly double that in the latest count, according to the conservation group WWF.
Neutral	Positive	But there are rules intended to conserve the land, protect the wildlife and keep dogs safe.
Neutral	Positive	Conservationists have to be serious about working with the ranching community to come up with creative ideas that are both economically and biologically sustainable.
Neutral	Positive	Fiona Gilmore, below right, is campaigning against plans to bring power lines through a wildlife habitat.
Neutral	Positive	For Greenpeace, the agreement offered a solution to one of the biggest causes of rainforest destruction: The cattle industry is responsible for up to 80 percent of the clearings in recent years, according to the Yale School of Forestry and Environmental Studies.
Neutral	Positive	In 2012, the federal government came up with a backup plan, designating private land in Louisiana as “critical habitat” for the frogs’ survival.
Neutral	Positive	Officials used new satellite technology to identify a site for the 250,000-acre operation that they said would do the least damage to biodiversity.
Neutral	Positive	Some of the others are designed to return natural flow to wetlands in the Everglades system.
Neutral	Positive	The Ecuadorean government, conservation groups and other organizations are working to develop a new sustainable plan for the Galapagos Islands.
Neutral	Positive	The money would go to programs like protecting ocean and air quality and wildlife and improving parks.
Neutral	Positive	The New York State Department of Environmental Conservation has introduced an effort to restore young forest areas, although the goal seems counterintuitive, cutting down forests to make room for new ones.
Neutral	Positive	Two years ago, the Mexican government imposed a two-year ban on all gillnets across 5,000 square miles of the vaquita habitat and sent its Navy to enforce it.

Table A.11: 100 Sentences from NYT (Cont.)

Code Label	Manual Label	Sentence
Neutral	Neutral	A cacophonous symphony of sights and sounds contrast control and freedom: barred prison windows versus open forests, faucets that gush like waterfalls versus boxes of rat poison.
Neutral	Neutral	A third biome, roofless, will house plants that thrive in the Cornish climate, including species from India, Chile and the Atlantic temperate woodlands as well as native flora.
Neutral	Neutral	In this complex scenario, a central piece of Mr. Lula's conservation strategy must involve the global market.
Neutral	Neutral	After the storm, as night began to fall on Saturday, one man, waiting with several others as the wildlife officers took boats into the bayou, said he spoke to the Littles by cellphone at 1 a.m. on Saturday and that they were safe.
Neutral	Neutral	It's a global sourcebook for people working in the science of biodiversity, and it's become a tool for conservationists, policy makers, wildlife regulators and forestry, customs and enforcement officials.
Neutral	Neutral	Approaching cedar forests, often the first trees you see are young.
Neutral	Neutral	As for undeveloped land zoned residential, 119 acres of it remain, and a portion consists of wetlands.
Neutral	Neutral	As species migrated from the Tethys (now the East Atlantic) to this area, the hot spot of marine life shifted.
Neutral	Neutral	At the end of the day, I watched the sun set over a rolling patchwork of farm fields and hardwood forests, before shimmying down Dynamite – a black diamond, by local standards at least – on my last run.
Neutral	Neutral	"I personally have seen bats fly toward the lunchroom and turn around, if any lights are on," said Myra Barnes, wildlife biologist for the park service at Carlsbad.
Neutral	Neutral	But as a child he was fascinated by wildlife, voraciously reading books and watching documentaries on the subject.
Neutral	Neutral	Case studies of office workers demonstrate that ecological design promotes communication and interaction and reduces stress, she said.
Neutral	Neutral	Chief among them is the understanding that ecological design is not simply about making buildings with minimal carbon footprints or trees on their facades.
Neutral	Neutral	Colombia's little-known Pacific coast is rugged and heartbreakingly beautiful, with islands that, like the better-known Galapagos to the south, are full of ecological wonders.

Table A.11: 100 Sentences from NYT (Cont.)

Code Label	Manual Label	Sentence
Neutral	Neutral	David E. Schimel, a lead author and director of a federal system of ecological monitoring stations, said in the call that mitigating emissions in the long run was still important even though not much could be done to change the short-term climate picture.
Neutral	Neutral	Dr. Kiers wants to know which fungi species are where, what they do, and which should be immediately protected.
Neutral	Neutral	Following one family's yearlong journey to find food and return home, "Polar Bear" is both a paean to a swiftly changing Arctic habitat and a deeply affecting story about fierce mother love.
Neutral	Neutral	Given the size of Patagonia – some 300,000 square miles of sweeping plains, mountainous forests and pristine waterways in Argentina and Chile – the itineraries below offer a well-rounded introduction to the region.
Neutral	Neutral	Under extreme threat, some animal species will freeze, playing dead.
Neutral	Neutral	In 10 or 15 years that habitat might revert to a forest.
Neutral	Neutral	In interviews with The Times, Toek Tik recently described how from 1977 to 1997, under the cover of Cambodia's decades of genocide and upheaval, he had systematically targeted temples and shrines in the nation's forests and jungles and fed the plundered statuary to dealers and brokers.
Neutral	Neutral	It is the only tropical rainforest within the U.S. Forest Service's holdings, not the only rainforest.
Neutral	Neutral	It undertook an elaborate – and fiercely contested – classification of all the private lands in the park, based on existing development, proximity to forest preserve and natural features like slopes, soil types and wetlands.
Neutral	Neutral	Mr. Barrett says that in fisheries, a demand-based society doesn't fit."It's wild and unpredictable," Mr. Barrett said.
Neutral	Neutral	A research assistant at the American Museum of Natural History, Mr. Bull led popular birding tours of Long Island and Central Park in the 1960's and 70's and meticulously kept track of the species and the state of their habitat.
Neutral	Neutral	Mr. Harris, who has blocked the opening of several Muslim prayer spaces, said white British natives were "an endangered species" in London.
Neutral	Neutral	Our Republican governor-elect, Pete Ricketts, is a member of the TD Ameritrade managerial family that constructed a LEED platinum-certified headquarters, indicating their commitment to renewable energy and conservation.

Table A.11: 100 Sentences from NYT (Cont.)

Code Label	Manual Label	Sentence
Neutral	Neutral	Netflix and its rivals consider wildlife programming a smart bet because it is appropriate for all ages and works well internationally.
Neutral	Neutral	No ecology is as fragile as a down-at-the-heels, out- of-the-way town discovered by hipsters.
Neutral	Neutral	Other scientists suggest that in rainforest plants, nyctinasty allows for maximum daytime sun exposure while folding sheds excess water at night.
Neutral	Neutral	The Supreme Court case boils down to this: Energy companies received a permit from the U.S. Forest Service allowing pipeline construction through national forests that the agency oversees.
Neutral	Neutral	Sauer even brought in a Finnish wildlife chef, Mika Manninen, to prepare the meal: salmon soup, eggplant lasagna and filet of beef.
Neutral	Neutral	In keeping with the ecology theme, the best man's daughters dressed up as an octopus and a shark and stood on the street with signs to direct guests.
Neutral	Neutral	She takes skinny stems of baby's breath, an invasive species prone to infesting vacant lots (and cheap deli arrangements) and other discarded varieties, and arranges giant cloud-shaped bouquets that she inverts and suspends from ceilings in a perforated chandelier, the flowers subordinate to the spaces between them.
Neutral	Neutral	She treats us to reverential romps through the forests of the American Northwest.
Neutral	Neutral	St. George developed around fisheries and granite quarries, but in the 20th century became a destination for urbanites heading north to escape summer heat.
Neutral	Neutral	Sunscreen manufacturers have also disputed the claims about the dangers to coral reefs.
Neutral	Neutral	The Amazon is the world's largest rainforest, and its protection is crucial to stopping catastrophic climate change because of the vast amount of carbon dioxide it absorbs.
Neutral	Neutral	The developer, Plum Creek, has proposed building two resorts and hundreds of houses near Moosehead Lake in the west central part of Maine, with additional land set aside for conservation.
Neutral	Neutral	The Dutch, with few forests left to burn, harvested enough peat in the 17th century to help usher in a golden age of wealth, science and art.
Neutral	Neutral	The group's executive director, Sean McMahon, said that many farmers were eager to employ conservation practices, but that education and time were needed to see more results.

Table A.11: 100 Sentences from NYT (Cont.)

Code Label	Manual Label	Sentence
Neutral	Neutral	Then there are the pledges from the sites to not just make money but to do good: they say they are helping to keep the artisans out of factories and sweatshops – and endangered habitats.
Neutral	Neutral	The resultant gunk is treated with gaseous ammonia to ensure that it's not a habitat for E. coli and other pathogens.
Neutral	Neutral	The scientists' most recent rainforest trips also yielded high-resolution video showing that several other ant species glide, as do the larvae of insects like grasshoppers and praying mantises.
Neutral	Neutral	The X-rays I photographed – both at the Getty museum and then at the Asian Art Museum of San Francisco – were elements of previously existing archives made for the purpose of art conservation.
Neutral	Neutral	These startlingly realistic vessels and objects sculpted or painted (or both) to mimic flora and fauna are seemingly everywhere, whether in the form of vintage pieces, those from traditional manufactories or collections created by a new wave of young makers.
Neutral	Neutral	Thomas Lovejoy, an American conservation biologist who was a driving force behind the first Earth Summit in 1992, said he remained discouraged by the lack of action in reducing carbon emissions.
Neutral	Neutral	To create portraits of all 15 species of cranes, Bateman traveled to the only place where they exist together, Wisconsin's International Crane Foundation, which serves as a species bank for threatened populations.
Neutral	Neutral	Urban forests – the forests and green spaces in cities and towns – have, on average, temperatures that are 2.9 degrees Fahrenheit lower than unforested urban areas, according to the Environmental Protection Agency.
Neutral	Neutral	We also saw guanacos, vicunas, wild donkeys, nesting Andean Tagua coots, Pato puna ducks with vivid blue bills, and a dozen other bird species, but very little human traffic.
Neutral	Negative	The groups had sued over the 10-year plan, arguing that it favored irrigation over sustaining the coho, a threatened species.
Neutral	Negative	More than three quarters of oceanic shark and ray species are now threatened with extinction, jeopardizing marine ecosystems and the food security of people in many nations.The research offers the latest data point in what is a dismal trajectory for Earth's biodiversity.
Neutral	Negative	If the planet heats even a half-degree more, it could lead to water and food shortages, mass extinctions of plants and animals, and more deadly heat and storms, scientists say
Negative	Neutral	Left, students rallied during a "Save the Tiger" conservation campaign this week in India.
Negative	Neutral	Arguing for bolder conservation efforts, like high fuel standards for cars, Mr. Boehlert said he worried that the gas and oil that might be recovered would be more valuable to the country in a time of emergency.

Table A.11: 100 Sentences from NYT (Cont.)

Code Label	Manual Label	Sentence
Negative	Neutral	Craig Bobzien, the acting deputy forest supervisor for the Bitterroot National Forest, said logging would prevent thousands of trees from blowing down and creating a fire threat for homes scattered throughout the ponderosa forests in a scenic mountain valley that has been a magnet for retirees and others seeking a rural existence.
Negative	Neutral	Last spring, the Virginia legislature passed a bill acknowledging that utility-scale solar can have a "significant adverse impact" on forests and farmland and creating an advisory panel to develop measures to reduce this impact.
Negative	Neutral	What I did see, however, within minutes of leaving the airport, was a kind of wildlife that had played no part in my childhood imaginings.
Negative	Negative	Economic growth is often seen as incompatible with conservation.
Negative	Negative	The policy reversal is a gift to the big game trade from Ryan Zinke, the interior secretary, who's apparently not satisfied with scrapping environmental and species protections on just one continent
Negative	Negative	Bloomberg traced aluminum used to make the F-150, Ford's electric pickup truck, to a polluting refinery in the Amazon rainforest.
Negative	Negative	But as a practical matter, the decision to uphold an owner's claim even when he had clear notice of the restrictions governing the property will make it more difficult and expensive for state and local governments to protect environmentally sensitive wetlands.
Negative	Negative	"Ecosystems also can collapse." He said that in discussing global warming, he refers not only to tipping points but to more general threats and that he was "not sure where the confusion about tipping points comes from." But other scientists, who study the response to climate change of polar ice and tropical forests, said that they saw scant evidence of runaway disruption.
Negative	Negative	In West Virginia, the Department of Natural Resources has lost at least $1.5 million in revenue from hunting and fishing licenses, which affects the department's ability to conduct conservation work, state officials said.
Negative	Negative	Intense drought fueled the flames this year, just as it did in previous American fires in the 1930's and again in 1988 – the year that shook our sense of immunity to global warming's impacts.The summer of 2000 will be remembered as a reminder of the need to protect habitat, wildlife and health.
Negative	Negative	Robin Silver, one of the founders of the group, described the wild cattle as "the biggest cause of endangerment of native wildlife in the West."
Negative	Negative	Some worry that wildlife along the Shawangunk Kill, a stream that flows through the area, will be threatened by the development.
Negative	Negative	The bird, which was taken to a wildlife rehabilitation organization last week, died earlier this week.

Table A.11: 100 Sentences from NYT (Cont.)

Code Label	Manual Label	Sentence
Negative	Negative	The bird, which was taken to a wildlife rehabilitation organization last week, died earlier this week.
Negative	Negative	Separately, ahead of a crucial climate summit in Glasgow, countries are gathering this week to try to stop a biodiversity collapse that many scientists say could equal climate change as an existential crisis.
Negative	Negative	The practice, which can kill marine life and disrupt fisheries, was blocked under the Obama administration.
Negative	Negative	They said the deaths had resulted from poor enforcement of wildlife laws requiring trawlers to stay several miles offshore during the turtle nesting season.
Negative	Negative	He acknowledged some of the country's problems, particularly with its forests, which remain under assault in many areas:For all the progress, we haven't always got things right.
Negative	Negative	Yet many populations of fish that have been the mainstay of the river's ecology are in decline.
Negative	Negative	Officials attributed the decline to conservation efforts, especially the installation of 1.7 million water-saving toilets and other plumbing fixtures.

Table A.12: Biodiversity Scores Rankings

GICS	Description	Avg.	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1010	Energy	23.3	23	24	23	24	22	24	23
5510	Utilities	21.9	24	23	24	19	17	22	24
6010	Real Estate	18.6	20	19	19	18	19	17	18
3020	Food, Bev. & Tobacco	18.4	17	20	20	23	24	6	19
3520	Pharma., Biotech., & Life Sc.	17.9	15	22	10	21	23	14	20
1510	Materials	16.7	22	2	22	22	20	8	21
2030	Transportation	14.7	19	5	14	20	16	7	22
2520	Consum. Durables & Apparel	14.4	14	21	17	14	13	21	1
2010	Capital Goods	12.3	13	9	15	10	7	15	17
4030	Insurance	10.4	11	14	1	17	18	11	1
3030	Household & Pers. Prod.	10.3	18	1	21	14	13	4	1
3510	Health Care Equip. & Serv.	9.6	12	7	1	13	21	12	1
2550	Retailing	9.6	10	10	13	7	10	16	1
4020	Diversified Financials.	9.3	9	6	12	11	8	18	1
2530	Consumer Services	8.7	21	3	18	7	10	1	1
2510	Auto & Components	7.4	1	12	1	14	13	10	1
4010	Banks	7.4	5	13	1	11	8	13	1
2020	Commercial & Prof. Serv.	7.4	16	4	16	6	6	3	1
5020	Media & Entertainment	6.6	1	18	1	1	1	23	1
4530	Semiconductors & Equip.	6.4	4	8	11	1	1	19	1
3010	Food & Staples Retailing	6.1	8	14	1	7	10	2	1
4520	Tech. Hardw. & Equip.	6.0	7	11	1	1	1	20	1
4510	Software & Services	4.7	6	14	1	1	1	9	1
5010	Communication Services	3.4	1	14	1	1	1	5	1

Note: Industry biodiversity scores measured by (1) 10K-Biodiversity-Count, (2) 10K-Biodiversity-Negative, (3) 10K-Biodiversity-Regulation Score, (4) Survey-Transition Score, (5) Survey-Physical Score, (6) Holding-based score, and (7) CDP-Biodiversity Score. The 10K-based Biodiversity Scores are averaged from 2015 to 2023. Survey-based Scores are from Q1 2023. Holding-based Score is from Q4 2023. CDP-based Score uses data from 2023. The industries are sorted by the average score across the seven measures.

Table A.13: Correlation of Survey-based Average Industry Rankings Across Subgroups

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Role											
(1) Academic	1.00										
(2) Private Sector	0.97	1.00									
(3) Public Sector	0.98	0.95	1.00								
Location											
(4) Asia	0.97	0.98	0.98	1.00							
(5) Europe	0.98	0.93	0.99	0.97	1.00						
(6) North America	0.99	0.99	0.97	0.98	0.95	1.00					
(7) ROW	0.96	0.91	0.93	0.90	0.94	0.94	1.00				
Concern											
(8) Very High	0.99	0.95	0.98	0.98	0.97	0.99	0.94	1.00			
(9) High	0.98	0.98	0.97	0.97	0.96	0.99	0.94	0.97	1.00		
(10) Low	0.98	0.99	0.96	0.97	0.94	0.99	0.94	0.97	0.98	1.00	
(11) No Concern	0.89	0.82	0.87	0.86	0.91	0.85	0.83	0.89	0.82	0.84	1.00

Note: Correlation of average industry rankings across different groups of survey respondents. The average survey score is computed as the average value of the transition score and physical score.

A.3 Separating Physical and Transition Biodiversity Risks

Beyond measuring aggregate biodiversity risk, we also seek to distinguish between physical and transition components. As discussed in Section 2, industries that rely heavily on natural capital face the greatest physical risks, whereas sectors with substantial land use are particularly exposed to transition risks arising from regulation, permitting, and land-use constraints. We therefore require a systematic method to quantify these two risk types over time and across industries.

Several studies have developed measures of aggregate physical and transition *climate risks*, often from news flows (e.g., Faccini et al. 2023), and of firm-level exposures to physical and transition climate risks (e.g., Sautner et al. 2023*a*). Most of these approaches rely on textual analysis, using methods such as machine-learning keyword discovery or Latent Dirichlet Allocation (LDA). In this section, we extend this literature by employing the state-of-the-art large language model GPT-4.0 to identify and quantify physical and transition *biodiversity risks*. Since its release, GPT-4.0 has been widely applied in finance, including to analyze firms' disclosure reports (e.g., Li et al. 2023) and to extract risks and market sentiment from news articles (e.g., Bybee 2023, Chen et al. 2022).

In this section, we propose measures of physical and transition biodiversity risks over time using NYT articles. Then, we describe new measures of firms' physical and transition risk exposures using firms' 10-K statements. Finally, we explore how the returns on portfolios sorted by physical and transition risks covary with the physical and transition risk series.

Measuring Aggregate Biodiversity Risks. The first step is to identify biodiversity-related articles in the NYT using regular expression searches based on the biodiversity dictionary (Appendix Table A.3). These identified articles are then provided to OpenAI's GPT-4.0, which is prompted to classify each article by category (physical vs. transition), direction (increase, decrease, neutral), and strength (extremely important, very important, moderately important, slightly important, not at all important). The prompt used to query GPT is detailed in Appendix Code 1. Each query to GPT includes the headline and the full text of the article. In response, GPT generates a string of text according to the requested format in the prompt. For instance, when presented with a news article about the significant weakening of the Endangered Species Act by the U.S., GPT identifies it as a significant decrease in biodiversity transition risk, likely increasing biodiversity physical risk. Similarly, when presented with an article about Biden's voiding of a Trump-era deal to open an Alaskan wildlife area, GPT identifies it as an increase in biodiversity transition risk and a decrease in biodiversity physical risk. Appendix Table A.16 provides further examples of headlines, leads, and related explanations, demonstrating the reasoning behind GPT's responses.

We aggregate article-level labels into daily time series for *physical* and *transition* biodiversity risks. Each article receives (i) a *mention* indicator (1 if the article mentions the risk, 0 otherwise) and (ii) a *risk-importance* rating on a 0–4 scale (4 = "extremely important," 0 = "not at all important"). The article-level score is the product of these two values, and the daily NYT-BD-Physical (NYT-BD-Transition) News Index equals the sum of scores across all articles published that day. For the NYT-BD-Physical Risk Index and NYT-BD-Transition Risk Index, we use the direction of risk ("+1" for increasing, "0" for neutral, and "-1" for decreasing) and multiply it by the strength. A score of "+4" represents the highest level of increasing risk, while a score of "-4" indicates the highest level of decreasing risk. We then sum all article-level scores within a day to obtain the daily risk score.

These daily measures can be easily aggregated to weekly or monthly levels by taking the average of the daily series. Appendix Figure A.15 plots the monthly indices. Physical risks are generally increasing, while transition biodiversity risks were generally decreasing during the years of the Trump administration (2017-2021).

Figure A.15: Biodiversity Physical and Transition Risks

Note: Monthly NYT-Biodiversity Risks indices between 2010 to 2023.

Appendix Table A.14 reports pairwise correlations among the biodiversity news indices using monthly data from 2010–2023. Column (1) shows the baseline NYT-Biodiversity News Index, and the remaining columns report the disaggregated indices. The correlation between the NYT-BD-Physical News Index and the NYT-BD-Physical Risk Index is 0.95, indicating that newspaper discussions of physical risks are tightly linked to concerns about biodiversity loss. By contrast, the correlation between the NYT-BD-Transition News Index and the NYT-BD-Transition Risk Index is only 0.12, suggesting that coverage of biodiversity-related policies reflects both tightening and loosening of regulations. Overall, the correlations in column (1) imply that the baseline NYT-Biodiversity News Index predominantly captures news about physical biodiversity risks rather than transition risks.

Table A.14: Correlation Across Measures of Aggregate and Disaggregate Risk

	(1)	(2)	(3)	(4)	(5)
Aggregate Measures					
(1) NYT-Biodiversity News Index	1.00				
Disaggregate Measures					
(2) NYT-BD-Physical News Index	0.34	1.00			
(3) NYT-BD-Physical Risk Index	0.40	0.95	1.00		
(4) NYT-BD-Transition News Index	0.15	0.49	0.39	1.00	
(5) NYT-BD-Transition Risk Index	−0.32	−0.15	−0.28	0.12	1.00

Note: Pairwise monthly correlation across biodiversity risk measures from 2010 to 2023.

Firm-Level Measures of Biodiversity Risk Exposures. Our firm-level measures of physical and transition biodiversity risk exposures are based on textual analysis of firms' 10-K statements. We identify biodiversity-related mentions using regular expression searches for the biodiversity dictionary in Appendix Table A.3. We focus on discussion in item 1 (Business), item 1A (Risk Factors), and item 2 (Properties), retaining the sentences that mention the keywords as well as the two preceding and two following sentences.

For each sentence and its surrounding context, we use GPT to assess whether the direct consequences of biodiversity and ecosystem services loss—i.e., physical biodiversity risk—create potential risks or opportunities for the firm's operations and financial outlook. In parallel, we ask whether greater regulatory stringency in biodiversity conservation and nature preservation—i.e., transition biodiversity risk—generates risks or opportunities. The exact prompt used is provided in Appendix Code 2. Based on GPT's classification, we assign a 10K-Biodiversity-Physical Score or 10K-Biodiversity-Transition Score of "+1" if the passage is identified as a risk and "–1" if it is identified as an opportunity. Appendix Table A.17 illustrates examples of 10-K discussions alongside GPT's responses.

To compare biodiversity risk exposures across industries using our various measures, we aggregate the firm-level scores to the industry level by summing the 10K-Biodiversity-Physical Score (10K-Biodiversity-Transition Score) for all firms within each industry. Appendix Figure A.16 shows the industry ranking based on physical and transition risks. The sectors with the highest biodiversity physical risk exposures are Food, Beverage & Tobacco, Materials, and Pharmaceutical, Biotechnology & Life Science, while the sectors most exposed to transition risk are Energy, Materials, and Utilities.

Appendix Table A.15 reports the cross-industry correlations of biodiversity exposures across different measures. The table highlights that our industry-level measures of biodiversity risk exposures are highly correlated. Specifically, both 10K-based and survey-based measures show strong correlations for physical and transition risks.

Table A.15: Industry-level Correlations of Biodiversity Scores

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Survey-based Scores								
(1) Survey: Physical	1.00							
(2) Survey: Transition	0.82	1.00						
(3) Survey: Average	0.96	0.95	1.00					
10K-based Scores								
(4) 10K: Physical	0.75	0.65	0.74	1.00				
(5) 10K: Transition	0.33	0.66	0.52	0.34	1.00			
(6) 10K: Average	0.38	0.69	0.55	0.41	1.00	1.00		
CDP-based Score								
(7) CDP	0.30	0.58	0.46	0.32	0.72	0.73	1.00	
Holding-based Score								
(8) Holding	0.02	0.26	0.14	0.11	0.32	0.32	0.33	1.00

Note: Industry-level Pearson correlations of Survey-based, 10K-based Biodiversity Scores, CDP Biodiversity Scores, and Holding-based Score. The 10K-based scores are averaged across 2015 to 2023. Survey-based Scores use data in Q1 2023. Holding-based Score uses data from Q4 2023. CDP-based Score uses data from 2023.

Hedge Performance. Appendix Figure A.17 presents the monthly correlations of various hedge portfolios with AR(1) innovations in biodiversity news and risk indices. Panel (a) displays the hedging performance of biodiversity portfolios against biodiversity news indices. Overall, biodiversity hedging portfolios perform well with respect to the NYT series they are designed to target. Physical risk portfolios formed using 10-K statements and survey responses, perform well in hedging biodiversity physical risk, whereas transition risk portfolios generally hedge transition risk well, though the differences between the hedge performances across different series is generally small.

Figure A.16: Industry Ranking based on 10K Biodiversity Risk Exposure

(a) Physical Risk

(b) Transition Risk

Note: Panel (a) shows the industry ranking based on the average 10K-Biodiversity-Physical Score from 2010 to 2023. Panel (b) presents the industry ranking based on the average 10K-Biodiversity-Transition Score over the same period.

Figure A.17: Biodiversity Hedge Performance of Various Portfolios

(a) Biodiversity News Indices

(b) Biodiversity Risk Indices

(c) Biodiversity Risk Indices (dropping 2017 to 2020 inclusive)

Note: Dot plot of monthly return correlations for various biodiversity hedge portfolios with AR(1) innovations of biodiversity indices. Panel (a) and (b) show the correlation with NYT-BD News indices and NYT-BD Risk indices respectively using data from 2010 to 2023. Panel (c) shows the correlations with NYT-BD Risk indices from 2010 to 2023, dropping the years 2017 to 2020 inclusive.

Panel (b) shows the correlations with biodiversity risk indices—recall that the difference to the biodiversity news indices is the attempt to separate whether a particular news article corresponds to being 'good news' or 'bad news.' While correlations with the NYT-BD-Physical Risk Index are generally positive, correlations with the NYT-BD-Transition Risk Index are negative. This might be explained by difficulties in interpreting the 'sign' of the transition news, in particular during the years of the Trump presidency, when there were frequent instances interpreted as 'good news' from a biodiversity transition risk perspective. For instance, reports of biodiversity policy relaxation can be followed by discussions of opposition, legal challenges, or potential policy reversals, as highlighted in the NYT article "*Trump's Environmental Rollbacks Were Fast. It Could Get Messy in Court.*"

In Panel (c), we exclude the years 2017 to 2020, during which the NYT-BD-Transition Risk Index fluctuated remarkably, moving from positive to negative and back to positive. Compared to Panel (b), portfolios show better hedging performance with respect to the NYT series they target. While the results are promising, they are somewhat mixed, suggesting that further extensions and refinements could be explored.

Table A.16: GPT classification examples: NYT

Panel A: Physical Risk Increases		
Fight Against an Invasive Fish Threatens a Fragile Unity in the Great Lakes (2010-01-03)	The State of Michigan is suing Illinois to close Chicago-area waterways that could allow Asian carp, a nonnative species that consumes the food of other fish, to reach Lake Michigan.	The Asian carp invasion threat in the Great Lakes underscores a significant risk to U.S. biodiversity, leading to legal actions and regional cooperation to prevent ecological and economic damage.
The Global Extinction Crisis (2021-09-29)	More than 20 species on the U.S. endangered list are now gone forever, officials said Wednesday. A million more are at risk.	The extinction of over 20 species in the U.S. underscores a significant national biodiversity crisis, with a million species at risk.
Mapping California's 'Zombie' Forests (2023-03-08)	A warming climate has left a fifth of the conifer forests that blanket California's Sierra Nevada stranded in habitats that no longer suit them, according to a study published last week by researchers at Stanford University.	California's Sierra Nevada faces a biodiversity crisis with 'zombie forests' indicating a severe risk to ecosystem services in the U.S.
Panel B: Physical Risk Decreases		
Biden Administration Sets a Mining Ban in Boundary Waters Wilderness (2023-01-26)	A 20-year moratorium on new mining activity for more than 225,000 acres of federal land in Minnesota could deal a fatal blow to a proposed Twin Metals copper-nickel mine.	The decision to establish a 20-year moratorium on mining in Minnesota, as discussed in the article, specifically addresses the conservation of the Boundary Waters Canoe Area Wilderness. This action directly impacts the United States by protecting a significant natural area, thereby reducing the risk of biodiversity loss and ecosystem service degradation within the country.
How California's Elephant Seals Made a Remarkable Recovery (2023-03-16)	Hunted nearly to extinction, northern elephant seals, native to the waters off the West Coast, now number more than 175,000.	Conservation measures in the United States have effectively increased the northern elephant seal population, indicating a positive impact on biodiversity.
Uptick Seen in Red Knots on Jersey Shore (2023-06-15)	An annual spring count instilled hope among biologists that the threatened shorebird may be recovering from recent declines. Crab harvesting bans were partly credited for the rise.	The focus on the recovery of shorebirds and horseshoe crabs in the United States, due to regulatory actions, indicates a declining risk of losing biodiversity and ecosystem services nationally.

Note: Panel A shows the articles classified by GPT as indicating increasing physical risk, while Panel B presents those indicating decreasing physical risk. Column 1 shows the headline and date, column 2 contains the lead sentences of the NYT news article, and column 3 presents the output of GPT Prompt 1.

Table A.16: GPT classification examples: NYT (Cont.)

Panel C: Transition Risk Increases		
White House Aims to Reflect the Environment in Economic Data (2023-01-20)	The Biden administration has set out to measure the economic value of ecosystems, offering new statistics to weigh in policy decisions.	The article discusses incorporating natural capital into economic calculations, a move towards recognizing and potentially enhancing biodiversity policy. The Biden administration's effort suggests a tightening of policy, very likely influencing operational strategies of companies, especially those reliant on natural resources.
Biden Voids Trump-Era Deal to Open Alaskan Wildlife Area (2023-03-14)	The administration canceled a plan that would have allowed road construction in Izembek National Wildlife Refuge.	The article discusses the Biden administration's decision to withdraw a land swap deal, protecting Izembek National Wildlife Refuge, indicating a tightening of biodiversity policy.
A 24-Armed Hunter, Threatened With Extinction, Is Set to Get Protection (2023-03-15)	Sunflower sea stars, huge starfish that until recently thrived in waters up and down the west coast of North America, are threatened with extinction and should be protected under the Endangered Species Act, federal officials said Wednesday.	The article discusses the proposal to list sunflower sea stars as threatened under the Endangered Species Act, indicating a tightening of biodiversity policy.
Panel D: Transition Risk Decreases		
U.S. Significantly Weakens Endangered Species Act (2019-08-12)	The Trump administration on Monday announced that it would change the way the Endangered Species Act is applied, significantly weakening the nation's bedrock conservation law and making it harder to protect wildlife from the multiple threats posed by climate change.	The article discusses weakening biodiversity policy by making it harder to protect wildlife, especially from climate change.
Trump Drilling Plan Threatens 9 Million Acres of Sage Grouse Habitat (2018-12-06)	The Trump administration on Thursday detailed its plan to open nine million acres to drilling and mining by stripping away protections for the sage grouse, an imperiled ground-nesting bird that oil companies have long considered an obstacle to some of the richest deposits in the American West.	The article discusses reducing protections for the sage grouse, indicating a loosening of biodiversity policy.
Trump Administration Loosens Sage Grouse Protections, Benefiting Oil Companies (2019-03-15)	The Trump administration on Friday finalized its plan to loosen Obama-era protections on the habitat of the sage grouse, an imperiled ground-nesting bird that roams across 10 oil-rich Western states.	The article discusses loosening protections for sage grouse, impacting biodiversity policy.

Note: Panel C shows the articles classified by GPT as indicating increasing transition risk, while Panel D presents those indicating decreasing transition risk. Column 1 shows the headline and date, column 2 contains the lead sentences of the NYT news article, and column 3 presents the output of GPT Prompt 1.

Table A.17: GPT classification examples: 10-K

Panel A: Biodiversity Physical Risk		
Food, Bev. & Tobacco	Water is a main ingredient in substantially all of our products, production of the agricultural ingredients and is needed in our manufacturing process. It also is critical to the prosperity of the communities we serve and the ecosystems in which we operate. Water is facing unprecedented challenges from overexploitation, increasing pollution and emerging awareness of potential contaminants.	The report directly links biodiversity loss (water scarcity and quality) to potential risks for operations and finances.
Pharma., Biotech., & Life Sc.	Other potential physical impacts include reduced access to high-quality water and the loss of biodiversity, which could impact future product development. These risks could disrupt our operations and supply chain, which may result in increased costs.	The report directly mentions risks related to biodiversity loss impacting operations and R&D.
Materials	Our operations and those of our suppliers are subject to climate change variations which can impact the productivity of forests, the abundance of species, harvest levels and fiber supply.	The report directly links biodiversity loss to potential risks like reduced fiber supply, impacting the firm's operations and finances.
Energy	Companys largest refinery is located about 10 miles southeast of New Orleans. The gradual loss of coastal wetlands in southeast Louisiana increases the risk of future flooding should storms such as Katrina recur.	The report directly links biodiversity loss (coastal wetlands) to increased flooding risk, affecting the firm's operations and finances.
Panel B: Biodiversity Physical Advantage		
Commercial & Prof. Serv.	We work with our customer to manage and comply with the nation's most important environmental laws, including the Endangered Species Act and the Marine Mammal Protection Act. We also provide ocean and coastal environmental planning, biological surveys and monitoring, habitat restoration and invasive species management.	The firm benefits directly from biodiversity loss through increased demand for its environmental compliance and sustainability services.

Note: Sentences classified as risk are assigned a score of 1, and sentences classified as an advantage are assigned a score of -1. Panel A shows the sentences that are classified as risk by GPT, while Panel B presents the advantage sentences. Column 1 shows the industry, column 2 contains the sentences in the 10-K report discussing biodiversity risk, and column 3 presents the output of GPT Prompt 2.

Table A.17: GPT classification examples: 10-K (Cont.)

Panel C: Biodiversity Transition Risk		
Energy	Regulations related to the protection of wildlife could adversely affect our ability to conduct drilling activities in some of the areas where we operate. Our operations can be adversely affected by regulations designed to protect various wildlife, including threatened and endangered species and their critical habitat.	The report highlights risks from increased regulatory stringency on nature preservation, affecting operations and finances due to constraints on exploration and production activities.
Materials	The Companys activities are subject to extensive laws and regulations governing the protection of the environment, natural resources and human health. These laws address protection of natural resources, fisheries and wildlife protection, endangered species and reclamation of lands disturbed by mining operations.	The report indicates potential risks from increased regulatory stringency on nature preservation and biodiversity, affecting costs and operations.
Utilities	The Companies are subject to extensive and evolving federal, state and local environmental laws, regulations and permit requirements relating to air and water quality, protected natural resources (such as wetlands, endangered species and other protected wildlife) and health and safety.	The report highlights risks from environmental regulations.
Real Estate	Threatened and endangered species restrictions apply to activities that would adversely impact a protected species or significantly degrade its habitat. A number of species on our timberlands have been, and in the future may be, protected under these laws.	The report highlights risks from regulatory changes on biodiversity conservation.
Panel D: Biodiversity Transition Advantage		
Commercial & Prof. Serv.	Our teams test and analyze air, water and soil to determine concentrations of contaminants, as well as the toxicological impact of contaminants on flora, fauna and human health.	Increased regulatory stringency on nature preservation likely boosts demand for the firm's environmental testing and analysis services.

Note: Sentences classified as risk are assigned a score of 1, and sentences classified as an advantage are assigned a score of -1. Panel C shows the sentences that are classified as risk by GPT, while Panel D presents the advantage sentences. Column 1 shows the industry, column 2 contains the sentences in the 10-K report discussing biodiversity risk, and column 3 presents the output of GPT Prompt 2.

GPT Prompts

Code Listing 1: Prompts for NYT Biodiversity News Index

```
prompt_sys = """
        You are GPT, an AI assistant from OpenAI, based on the GPT-4 large language model architecture,
            released 2023, using pretrained knowledge up to April 2023.
    """

prompt = """
        Here is a news article:

        "%s"

        Please answer the following questions and return JSON:

        {'Q1': '(choice id)'};
        {'Q2': '(choice id)'};
        {'Q3': Answer Q3 (less than 80 words)};

        Q1: Based on the article, how would you summarize the news about the risk of losing biodiversity and
            ecosystem services in the United States?
        (a) Increase - The article suggests a rising risk of losing biodiversity and ecosystem services in the
            United States.
        (b) Decrease - The article suggests a declining risk of losing biodiversity and ecosystem services in the
            United States.
        (c) Neutral - The article includes a discussion of the risk of losing biodiversity and ecosystem
            services in the United States, but the direction is neutral or unclear.
        (d) No information - The article does not discuss the risk of losing biodiversity and ecosystem services
            in the United States.


        Q2: How important is this news in helping an analyst understand the risk of losing biodiversity and
            ecosystem services in the United States? Assign greater signal strength to nationally relevant
            information and lower signal strength to information about regional and local levels.
        (a) Extremely important
        (b) Very important
        (c) Moderately important
        (d) Slightly important
        (e) Not at all important

        Q3: Provide detailed explanations on Q1 and Q2.

        Biodiversity policy refers to the set of laws, regulations, guidelines, and practices designed to
            conserve and manage biodiversity. This includes the protection of species, habitats, and ecosystems
            to ensure their sustainability and resilience. Please exclude assessments of indirect elements, such
            as climate change policy.

        Please answer the following questions about biodiversity policy and return JSON:

        {'Q4': '(choice id)'};
        {'Q5': '(choice id)'};
        {'Q6': '(choice id)'};
        {'Q7': Answer Q7};
```

```
        Q4: Does this article explicitly discuss biodiversity policy, or factors related to biodiversity policy?
        (a) Yes
        (b) No

        Q5: Does this article indicate a tightening or loosening biodiversity policy?
        (a) Tightening
        (b) Loosening
        (c) Neutral - The article does not provide specific details or evidence regarding changes in biodiversity
            policy.

        Q6: How important do you anticipate the impact of this news about biodiversity policy will be on the
            market prices and operational strategies of exposed companies?
        (a) Extremely important
        (b) Very important
        (c) Moderately important
        (d) Slightly important
        (e) Not at all important

        Q7: Provide detailed explanations on Q4 to Q6, identifying specific parts of the article or exact
            policies discussed that contribute to this score. The explanation should be concise and precise,
            directly relating to the aspects mentioned in the article. (less than 50 words)};
    """
```

Code Listing 2: Prompts for 10K-based Biodiversity Scores

```
prompt_sys = """
        You are GPT, an AI assistant from OpenAI, based on the GPT-4 large language model architecture, released
            2023, using pretrained knowledge up to April 2023.
            """

    prompt = """
        Please read through this passage from a firm's 10-k report and analyze the firm's risk and opportunity
            regarding biodiversity loss.

      Here is an excerpt from a firm's 10-k report:

        <article>
        %s
        </article>

         Please answer all the questions and return JSON.

         {'Q1a': '(choice id)'};
         {'Q1b': '(choice id)'};
         {'Q2': Answer Q3};

         {'Q3a': '(choice id)'};
         {'Q3b': '(choice id)'};
         {'Q4': Answer Q6};

         Q1a: Based on the 10-k report, do the direct consequences of biodiversity and ecosystem services loss create
             potential advantages for the firm's operations and financial outlook, such as an upsurge in demand for
             the company's products and services?
         Exclude assessments of indirect elements, such as environmental regulations linked to the firm's effects on
```

biodiversity and ecosystems.

(a) Yes

(b) No information

Q1b: Based on the 10−k report, do the direct consequences of biodiversity and ecosystem services loss pose potential risks for the firm's operations and financial outlook, such as declining availability of raw materials, potential supply chain disruption, and diminished sources for R&D?

Exclude assessments of indirect elements, such as environmental regulations linked to the firm's effects on biodiversity and ecosystems.

(a) Yes

(b) No information

Q2: Provide detailed explanations on Q1a and Q1b.

The explanation should be concise and precise, directly relating to the aspects mentioned in the 10−k report. Please summarize the essential details in a single bullet point of fewer than 50 words.

Q3a: Based on the 10−k report, impact of increased nature preservation and biodiversity conservation regulatory stringency creates potential advantages for the firm's operations and financial outlook?

(a) Yes

(b) No information

Q3b: Based on the 10−k report, impact of increased nature preservation and biodiversity conservation regulatory stringency poses potential risks for the firm's operations and financial outlook?

(a) Yes

(b) No information

Q4: Provide detailed explanations on Q3a and Q3b.

The explanation should be concise and precise, directly relating to the aspects mentioned in the 10−k report. Please summarize the essential details in a single bullet point of fewer than 50 words.

"""

A.4 Additional Data Details

A.4.1 Surveyed Public Sectors

We gathered email addresses from a range of institutions that make researcher emails accessible on their institutional websites. The institutions are Banco Central de Chile, Banco Central de Reserva del Perú, Banco Central do Brasil, Banco de España, Banco de la república Colombia, Banco de México, Bangko Sentral ng Pilipinas, Bank for International Settlements, Bank Negara Malaysia, Bank of Canada, Bank of England, Bank of Finland, Bank of Israel, Bank of Japan, Bank of Korea, Banque de France, Central Bank of Malta, Central Bank of Thailand, Danmarks Nationalbank, De Nederlandsche Bank, Deutsche Bundesbank, European Central Bank, Federal Reserve Banks of Boston, Federal Reserve Banks of Chicago, Federal Reserve Banks of Dallas, Federal Reserve Banks of Minneapolis, Federal Reserve Banks of New York, Federal Reserve Banks of Philadelphia, Federal Reserve Banks of Richmond, Hongkong Monetary Authority, International Monetary Fund, National Bank of Georgia, Norges Bank, Reserve Bank of Australia, Reserve Bank of India, Reserve Bank of South Africa, United Nations, World Bank, World Economic Forum.

A.4.2 Biodiversity Sentences

We define the Biodiversity Dictionary in Appendix Table A.3. While certain unigrams, such as deforestation, effectively identify biodiversity sentences, others are not as precise due to their broad connotations. For example, the word "ecosystem" can also be used in the context of describing "software ecosystems", as illustrated in the following example: "Our products primarily compete based on performance, energy efficiency, integration, ease-of-use, innovative design, features, price, quality, reliability, security features, **software ecosystem** and developer support, time-to-market, brand recognition, customer support and customization, and availability."

To avoid selecting sentences that are irrelevant to biodiversity, we employ other terms to narrow down the sentences for these particular words. A sentence will be classified as being related to biodiversity only if it contains both the specific biodiversity vocabulary and one of the following terms simultaneously. For example, a sentence will be selected if it contains both "ecosystem" and "climate": "We understand the adverse effects of human behavior and **climate** change on **ecosystems** and the animals who call them home; therefore, we are constantly working to minimize the footprint of our operations."

- **Ecosystem(s):** climate, coast, forest, micro, natur, public health, sustaina, water

- **Species:** aquatic, biodiversity, bird, endanger, environment, fish, habitat, invasive, list, marine, protect, threat, ESA, EPA

A.4.3 P-value Adjustment for Multiple Testing

In this section, we apply the Benjamini-Hochberg method (Benjamini & Hochberg (1995), BH) to study the statistical significance of the correlation between hedging portfolios sorted on the 212 stock characteristics and biodiversity risk innovations. The key idea of BH is to adjust the statistical significance threshold in a way that guarantees a "false discovery rate" control. That is, having chosen a threshold τ, the adjustment guarantees that in expectation, at most a fraction τ of the tests that are deemed significant by the test are in fact false positives (for more details, see Giglio, Liao & Xiu 2021).

To apply the BH procedure, we proceed as follows. First, we compute the (univariate) correlation between each of the hedging portfolios sorted on the 212 stock characteristics and the innovation of the NYT Biodiversity Risk Index over the period of 2010 to 2023 and get the standard p-values for the statistical test that these correlations are not zero. Then we sort all the p-values in ascending order, denoted as $p_{(1)} \leq ... \leq p_{(N)}$. The BH procedure recommends rejecting the null hypothesis that the correlation is zero, for each $i = 1, ..., N$, if $p_i \leq p_{(\hat{k})}$, where $\hat{k}$= max $\{i \leq N : p_{(i)} \leq \tau i/n\}$. In this test, N is 212 and we set τ to be 0.05 (the false discovery rate). We find that *none* of the 212 characteristics has a correlation lower than the cutoff, suggesting that the good hedging performance observed for some measures is the product of random chance.

To visualize these results, we plot the p-value ($p_{(i)}$) for each for each correlation i and the corresponding threshold ($\tau i/n$), where i is the position in the ordering. Appendix Figure A.18 illustrates that none of these p-values is below the threshold. Meanwhile, the p-value of the portfolio built using our average biodiversity risk measure is 0.005, below the 0.05 threshold. We do not adjust this p-value since our measures are economically motivated a priori.

This test suggests that none of these common factors in the factor zoo captures biodiversity risks and has a significantly non-zero correlation with innovations in the biodiversity risk index. In contrast, our economically motivated biodiversity measure shows significant hedging performance.

A.4.4 Biodiversity Risk Exposures Across Industries

In this section, we further explore how biodiversity risks impact industries with high exposure.

Figure A.18: Adjusted P-values Distribution

Note: The gray dots illustrate the p-values of the 212 characteristics using data from 2010 to 2023. The red line represents the corresponding threshold for each correlation.

Materials. Materials industries, such as mining, timber, and construction, face a variety of biodiversity risks. Appendix Figure A.9 shows that the Paper & Forest Products, Construction Materials and Metal Mining subsectors have particularly high biodiversity risks. Physical risks can impact the availability and quality of raw materials, such as timber from deforestation. In addition, regulations and legal and reputation risks represent additional exposures for this industry. Examples of firms in the materials sector describing their biodiversity risk exposures include:

> Federal and state requirements to protect habitat for threatened and endangered species have imposed restrictions on timber harvest on some of our timberlands, and these protections may be expanded in ways that further affect our operations. These actions may increase our operating costs; further restrict timber harvests or reduce available acres; and adversely affect supply and demand more broadly across our markets. [Pope Resources Ltd Partnership, 2015 10-K filing]

> In addition, the Company's existing mining operations may become subject to additional environmental control and mitigation requirements if applicable federal, state and local laws and regulations governing environmental protection, land use and species protection are amended or become more stringent in the future. [Stillwater Mining Co, 2012 10-K filing]