Biodiversity and firm performance: Empirical evidence in Japan

Katsuyuki Kubo[a], Thanh Thi Phuong Nguyen[b]

[a]*Faculty of Commerce, Waseda University, Japan*

[b]*Rikkyo University, Japan*

ABSTRACT

This research investigates the relationship between biodiversity and firm value, using data from Japanese listed firms. Our database covers about 1,480 firm-year observations with information on 355 individual firms in Japan from 2018 to 2023. We examine the effects of Corporate Biodiversity Footprint (CBF), the biodiversity loss caused by firms' business activities, on firms' financial performance measured by ROA, ROE, and Tobin's Q. We find that CBF has a positive relation with ROA, indicating that firm operation benefits from natural resource exploitation. We also examine the effects of Corporate Biodiversity Dependency on firms' financial performance and find a negative relation with ROA. The collapse of the ecosystems, together with increased regulations, will damage firms' operating profit.

JEL classification: L25; G32; G38

Keywords: Corporate Diversity Footprint; Corporate governance; Firm performance; Japan

---

* The Japan Society financially supported this research for the Promotion of Science (JSPS) KAKENHI Grant Nos. 23K01456 and 19H00603 (Katsuyuki Kubo) and Waseda University Grant for Special Projects No. 2023C-073 (Katsuyuki Kubo). Corresponding author at: Faculty of Commerce, Waseda University. 1-6-1 Nishiwaseda, Shinjuku-ku, Tokyo 169-8050, Japan. *E-mail address*: kkubo@waseda.jp (Kubo)

1. Introduction

This paper examines corporate biodiversity risk's impact on firm performance. Climate change already impacts our daily lives and will continue to do so for the foreseeable future. Yet, another equally important issue that has been neglected so far is *biodiversity loss*. Biodiversity is the shortened form of "biological diversity," defined as the variability among living organisms from all sources, including diversity within species, between species, and ecosystems (CBD[1], 1992). Humans depend on biodiversity, which contributes to securing safe water and food that are indispensable for survival.

As documented in various reports, biodiversity is in crisis. Species extinction caused by humans is 1,000 times faster than the typical extinction rate in Earth's history. Governments and global organizations have increasingly raised awareness of biodiversity loss and called for active protection via various policies in recent decades. In 2022, the Kunming-Montreal Global Biodiversity Framework (GBF) was adopted by some 200 countries, aiming to halt and reverse biodiversity loss by 2030. In business, on 25 January 2024, the Global Reporting Initiative (GRI) published "GRI 101: Biodiversity 2024" to help entities disclose their most significant impacts on biodiversity, which is effective from 1 January 2026. However, it is unclear whether the private sector, which benefits from, exploits, and impacts natural resources, recognizes the problems and takes necessary actions. Firms in industries heavily dependent on biodiversity, such as forestry, agriculture, fishery, and aquaculture, do not know "how much our loss is due to biodiversity collapse." At the same time, WEF (2020) provided evidence that protecting and restoring natural ecosystems can lead to economic growth and create new business opportunities. The report also emphasized the private sector's vital role in maintaining

[1] https://www.cbd.int/doc/legal/cbd-en.pdf

sustainable nature. This research, therefore, provides empirical evidence to answer the scientific question: *What is the financial impact of biodiversity loss on firm value?*

Although the interest in biodiversity finance increased, this research area is still very young. The link between biodiversity and finance used to receive little attention from academics due to the complexity of the topic and the lack of firm-level data on biodiversity. So far, firm-level data are obtained from secondary data provided by ESG rating agencies, such as the MSCI ESG Rating database, Bloomberg Terminal, or primary data collected from limited firms' sustainability reports. There is a call for more research on biodiversity finance (Karolyi and Tobin, 2023).

One of the difficulties of analyzing the relationship between company biodiversity exposure and their performance is that the effect can be both positive and negative. Firms may increase profit by overexploiting ecosystem services or reducing the cost to preserve biodiversity. If this is the case, there is a positive relationship between biodiversity use and firm performance. At the same time, companies with high biodiversity risk require external funding and have high capital costs (Li et al., 2025). A company will suffer significant losses if it loses access to those resources or services. According to this view, the relationship between the dependency on biodiversity and firm value could be negative. We utilize two distinct variables that measure the firms' use of biodiversity and the dependency on it to entangle the relationship.

This research investigates the impact of biodiversity on firm value, using data from Japanese listed firms. Our paper has a strong scientific significance as we introduce novel measures of biodiversity use and measures of firms' and industries' dependency on these risks. Our research originality lies in two main variables, Corporate Biodiversity Footprint (CBF)

and Biodiversity Dependency Score, developed by Iceberg Data Lab[2]. The *CBF* aggregates the biodiversity loss caused by a firm's annual activities related to land use, greenhouse gas (GHG) emissions, water pollution, and air pollution. To quantify the biodiversity loss caused by a specific firm, the CBF builds on the concept of Mean Species Abundance (MSA), which measures the relative abundance of native species in ecosystems compared to their abundance in undisturbed ecosystems. An MSA of 0% has wholly lost its native biodiversity, while one with an MSA of 100% is considered equal in biodiversity to an ecosystem undisturbed by human activities. CBF quantifies not only the direct impact of a firm but also the biodiversity loss along the entire value chain. Thus, the CBF contains scope 1, 2, and 3 components. The second biodiversity variable is the *Dependency* score in percentage, which is the weighted average of three dependency scores of the firm on the cultural ecosystem services, provisioning ecosystem services, and regulating ecosystem services. *Dependency* indicates the extent to which a company is dependent on ecosystem services.

We examine the effects of CBF and firm biodiversity dependency on firms' financial performance, proxy by ROA, ROE, and Tobin's Q. We also investigate the moderating role of firms' characteristics (ex., composition of boards of directors, CSR committee existence, institutional ownership, leverage) on the relation between biodiversity and firm value. Our database covers 1,480 firm-year observations with complete information on 355 individual firms in Japan from 2018 to 2023.

The first contribution of this paper is that we distinguish the use of biodiversity and the dependency on it. There are several studies on the effect of biodiversity on firm performance or stock market return (Li et al., 2025; Cheong et al.,2024; Kalhoro and Kyaw, 2024; Ma et al., 2024; Garel et al., 2024; Xin et al., 2023; Bach et al., 2024). The results are mixed. For example,

[2] https://www.icebergdatalab.com/

Garel et al. (2024), who examine the stock market return on biodiversity-related policy changes, find a positive relationship between the CBF and stock returns. In contrast, Xin et al. (2023) and Bach et al. (2024) show a nonsignificant or negative relationship between biodiversity exposure and firm performance. One possible reason for mixed results is that there are several mechanisms through which biodiversity affects firm performance, and the effect can be positive or negative, according to the mechanisms. By using two different measures, we can understand the impact of the use of biodiversity and that of the dependency of it.

Second, as far as we know, no existing research in the finance area in Japan provides empirical evidence of the direct impact of biodiversity loss on firm performance. Current literature either used cross-country data or the data of the U.S., and very few papers use data from other countries (Giglio et al., 2023; Flammer et al., 2023; Bassen et al., 2024; Garel et al., 2024; Kulionis et al., 2024; Coqueret et al., 2025; Li et al., 2025). Japan is one of the most biodiverse regions in the world, and biodiversity loss prevention is a significant issue. According to CBD (Convention on Biological Diversity), between 2007 and 2012, the number of threatened species identified in the Japanese Red List increased from 3,155 to 3,597[3]. In addition, the Japanese government is actively preserving biodiversity, as shown in the following sections4.

Our main findings show that Japanese firms have large biodiversity footprints. However, the loss is significantly contributed by Scope 3, which indicates that firms do not directly impact the environment. Second, the most significant impact on biodiversity is caused by land use and water pollution. Third, corporate biodiversity footprint positively relates to ROA,

[3] There is a decline of living organisms from remote islands, such as the Iriomote wildcat on Iriomote Island, the Ogasawara shrew in the Ogasawara Islands or the Yaku gecko on Yaku Island to almost the whole of Japan, from Hokkaido to Okinawa. Indeed, the Red List identifies, as endangered species, over 20% of mammals and vascular plants, over 10% of birds, and about 30% of reptiles, amphibians, and freshwater fishes. About one-third of the waterweed species in Japan are designated as threatened, and many other endangered species live in the waterside environment.

[4] https://www.cbd.int/countries/profile?country=jp

indicating that firm operation benefits from natural resource exploitation. Fourth, corporate biodiversity dependency has a negative impact on firms' operating performance. Japanese firms in our sample suffer from both physical and transition biodiversity-related risks. The collapse of the provisioning ecosystems will damage firms' operating profit. Therefore, firms need to conserve biodiversity in order to sustain their business in the long-term.

The remainder of the paper is structured as follows. Section 2 provides a literature review. Section 3 details the data and methodology. Section 4 presents in detail the summary statistics. Section 5 presents the empirical results and robustness check analyses. Section 6 concludes the paper.

2. Biodiversity and firm performance: literature review and institutional framework

2.1 Literature review

Mainstream accounting and finance journals so far are largely silent on biodiversity. Guer et al. (2024) conducted a bibliometric analysis of biodiversity in the areas of accounting, economics, and finance from 1995 to 2023 and identified 334 articles, which were mainly published in journals of environmental economics. Among the most related papers studying economic aspects of biodiversity loss, Dasgupta (2021) presents an overview of the current state of global biodiversity and the economic factors that contribute to its decline.

Biodiversity and firm performance

Several studies examine the effect of firms' biodiversity exposure on firm performance and value, though the results are not conclusive. Li et al. (2025) analyze the relationship between biodiversity risk and corporate efficiency using 23,750 firm-year observations from 2001 to 2020. The biodiversity variable is based on a text analysis of 10-K filings. The results show that the efficiency of companies with biodiversity risk is low. This effect is particularly

pronounced in companies with higher idiosyncratic volatility[5]. A working paper by Xin et al. (2023) showed no statistically significant relationship between biodiversity exposure and a firm's performance measured by ROA, firm earnings, and firm profit margin. On the other hand, Bach et al. (2024) documented a negative relationship. Cheong et al. (2024) empirically analyze the relationship between firms' activity to reduce negative impacts on biodiversity and their performance. Using panel OLS and dynamic GMM analysis of 648 tourism-related companies in the United States from 2001 to 2020, they show that attempts to maintain biodiversity are positively related to corporate profitability and cash flow.

Regarding the body of literature on investors' biodiversity pricing, literature so far provides a consistent finding that stock portfolios can be sensitive to biodiversity risk (Ma et al., 2024). Giglio et al, (2023) constructed measures of U.S. firms' biodiversity risks from a binary firm-level indicator for disclosures in 10-Ks. They found that returns covary positively with biodiversity news. Garel et al. (2024) used corporate biodiversity footprint (CBF) data to explore whether investors price this footprint. They find a positive relationship between the CBF and stock returns following major biodiversity-related policy changes such as the Kunming Declaration and the launch of the Taskforce for Nature-related Financial Disclosures (TNFD).

Bassen et al. (2024) provided evidence that strong biodiversity management is negatively associated with firms' stock price crash risk. Recently, Coqueret et al. (2025) showed that U.S. firms with a high biodiversity footprint in industries highly exposed to biodiversity-related risks exhibit higher expected returns.

[5] Specifically, the study examines whether the filings contain words related to biodiversity and regulation. The indicator assumes a value of one if a firm's 10-K report mentions biodiversity at least twice and regulation at least once; otherwise, it is 0. Previous studies have also used this method (Liang et al., 2024; Ahmad & Karpuz, 2024). Efficiency is calculated using the Data Envelopment Analysis method based on Demerjian et al. (2012).

Kalhoro and Kyaw (2024) empirically analyze the impact of the Kunming Declaration of 2021 and the 15th Conference of the Parties (COP15) of the United Nations Convention on Biological Diversity in 2022 on the stock price returns of American companies. Specifically, they focus on the impact on stock price returns of American companies responding to biodiversity risks and those not responding well. Before the first event, the Kunming Declaration, abnormal stock price returns for companies dealing with biodiversity were positive, but the excess returns after the event were not significant. In the case of the second event, the Montreal Conference, abnormal stock price returns for companies dealing with biodiversity were positive both before and after the event. In the industry-level analysis, stock price returns for industries facing biodiversity risk fell before and after the Kunming Declaration[6].

Research so far mainly used cross-country data or data from the U.S. firms, there are few empirical findings from Asian countries. He et al. (2024) analysed the annual reports of more than 4,000 Chinese companies spanning a 15-year period and revealed that substantial exposure to biodiversity risks among Chinese companies exceeded levels observed in the USA.

Determinants of Biodiversity Disclosure

Not all firms disclose their information on biodiversity voluntarily[7]. Addison et al. (2018) assessed the top 100 of the 2016 Fortune Global 500 companies' sustainability reports to gauge the current state of corporate biodiversity accountability. The authors found that almost half

[6] Here, companies with positive statements (score 1-8) are classified as companies that are dealing with biodiversity (172 companies), and companies with negative statements are classified as companies that are not dealing with it (48 companies). The first event day is October 13, 2021, the day of the Kunming Declaration, and the second is December 19, 2022, the day of the second part of COP15 in Montreal. The estimation window is 250 days, excluding 41 days before the event, and the event window is ±7 days around the event. Based on Giglio et al. (2023), they classify the text on biodiversity in the 10-K report as positive, negative, or neutral.

[7] We may have it from 2026 as this year the Global Reporting Initiative published GRI 101: Biodiversity 2024 to help organizations disclose their biodiversity impacts. The new standard is effective from January 1, 2026. It is important to understand the motivations for firms' voluntary corporate disclosure on biodiversity, because they have a bearing on the quality of the disclosures and the extent to which various stakeholders can rely on them to make decisions.

(49) of the Fortune 100 mentioned biodiversity in reports, while 31 made clear biodiversity commitments, of which only 5 were specific, measurable, and time bound. Although a variety of biodiversity-related activities were disclosed (e.g., managing impacts, restoring biodiversity, and investing in biodiversity), only 9 companies provided quantitative indicators to verify the magnitude of their activities (e.g., area of habitat restored). Focusing specifically on water information disclosure, Zhang, Tang, & Huang (2021) examine the factors affecting "water-sensitive" firms' decisions to disclose water-related information. They finding that the force of country-specific disclosure legislation does not have a significant impact on the link between water disclosure and self-regulation. The highest water-using firms make public disclosures as they are already subject to mandatory disclosure regulations, moderate performers make private disclosures of partial information to specific groups of analysts and shareholders, while the weakest make none.

Several studies have focused on the determinants of biodiversity disclosure. Using the data from 13 European countries from 2002 to 2016, Haque and Jones (2020) empirically analyze the relationship between diversity on the board and biodiversity disclosure, finding that companies with a high proportion of women on their boards of directors tend to disclose information on biodiversity. This trend is stronger among companies participating in the Global Reporting Initiative (GRI) framework. In addition, the GRI framework and the EU strategic plan positively impact the disclosure of biodiversity initiatives (DBI).

Biodiversity finance

The link between biodiversity and finance has only received attention recently by academics. Most significant works were published in the last two years after the call for more research in biodiversity risks by Karolyi and Tobin-de la Puente (2022). Other studies have investigated on the use of private capital to finance biodiversity conservation and restoration (see, e.g., Flammer et al., 2023). Hoepner et al. (2023) examined infrastructure firms, demonstrating that

those with more effective biodiversity risk management experience better financing conditions than peers.

No academic studies provided detailed material financial costs incurred by individual companies. We find the report of BloombergNEF illustrating the real financial costs incurred related to biodiversity. BloombergNEF (2023) profiled 10 companies that incurred financial losses as a result of poorly handled interactions with nature. The report documented that all sectors are exposed to nature risk, either physical risk or transition risk or both. For example, poultry producer Bernard Matthews lacked inadequate biosecurity measures, which enabled avian influenza to enter and spread throughout its supply chain, causing millions of pounds in lost sales and tainting its brand. This is an example of physical biodiversity risk facing by firms. On the other hand, transition risk features more prominently than physical risk, with policy and legal risk manifesting in five of the 10 cases. For example, 3M, a producer of chemicals has released toxic substances into watercourses and must pay $10.5 billion in legal liabilities. Smith et al. (2020) used 10 publicly available case studies, covering businesses of various sizes, from multiple sectors, operating in different contexts and demonstrated that business actions can contribute to the strategic goals and improve firms' value.

2.2 Biodiversity in Japan

2.2.1 The policy by the Japanese government

Japan is one of the countries that has made significant strides in biodiversity conservation. It actively engages with international collaborations such as the Convention on Biological Diversity, Kunming-Montreal Global Biodiversity Framework, the Global Reporting Initiatives. Remarkably, Japan has a strong legal framework on biodiversity. Notably,

the Nature Conservation Law[8] and the Basic Act on Biodiversity provide the legal basis for protecting and managing natural resources and natural ecosystems. The Nature Conservation Law, introduced in 1972, makes provision for the designation of, and for the determination of conservation plans relating to the three areas: wilderness areas, nature conservation areas and prefectural nature conservation areas. The Basic Act on Biodiversity[9], dated 2008, clarifies the fundamentals principles for conservation and sustainable use of biodiversity. Most recently, in 2023 the Cabinet approved the National Biodiversity Strategy and Action Plan (NBSAP) 2023-2030. NBSAP[10] is the sixth edition of Japanese National Biodiversity Strategy, which was first published in 1993. This NBSAP consists of two parts: the Strategy (Part 1) and the Action Plan (Part 1). Part 1 describes the status and issues of biodiversity and ecosystems services in Japan. It also lists five basic strategies which are subdivided into 15 state-oriented targets and 25 action-oriented targets with the vision to halt and reverse biodiversity loss by 2030. Part 2 describes the action plan including 367 relevant measures to be undertaken by FY2023 to achieve the targets specified in Part 1.

According to the NBSAP, Japan has a diverse environment with the rates of endemism (terrestrial mammals, amphibians and reptiles, and vascular plants) are outstandingly high when compared with other countries with large-scale economies. On the other hand, biodiversity loss has been continuing in Japan. For example, the habitat quality is declining owing to a lack of labor to manage farmlands, canals, and forests. The amount of agricultural,

[8] https://faolex.fao.org/docs/pdf/jap95113.pdf

[9] https://www.japaneselawtranslation.go.jp/en/laws/view/3892/en#:~:text=Article%2014(1)The%20State,and%20those%20that%20are%20important

[10] https://www.env.go.jp/en/nature/biodiv/nsj/

forestry, and fishery products has decreased due to increased imports from overseas. The capacity of forests to absorb greenhouse gases and purify water has been declining.

2.2.1 Biodiversity and business in Japan

Like other large economies, Japan faces challenges in balancing biodiversity conservation with economic development. The country has long asked all actors to take actions toward the realization of a “society in harmony with nature”, especially business operators. In 1992, Keidanren (Japan Business Federation), Japan's most prominent economic organization, established the Keidanren Nature Conservation Fund and Management Council, which raises awareness, promotes nature conservation activities, and supports nature conservation projects. In 2003, Keidanren also announced the Keidanren Nature Conservation Declaration, and in 2009, the Keidanren Declaration for Biodiversity and Guideline. The Keidanren Declaration for Biodiversity and Guideline was subsequently revised in 2018 and 2023 (Keidanren, 2023). It states, "As companies, our role in building a society in harmony with nature will be to provide goods and services and conduct R&D that steadily reduce negative impacts on natural capital including biodiversity and ecosystems inside and outside Japan, and instead contribute to increasing positive impacts. In addition, we will take action to conserve and restore natural capital including biodiversity and ecosystems not only within our group companies, but also throughout our supply chains."

Nine guidelines have been established based on this approach. The guidelines include, for example, understanding and managing the relationship between business activities and biodiversity, fair and equitable use of genetic resources, and measures to mitigate biodiversity loss (Keidanren, 2023).

Keidanren conducted a questionnaire survey in 2023 to examine the biodiversity situation among Japanese firms, through which they received responses from 326 companies out of 1529

member companies (Keidanren Committee on Nature Conservation, 2023a). This survey shows that many Japanese companies have a certain level of understanding of biodiversity. One of the questions asked was what percentage of managers and employees understood the meaning of biodiversity. Sixty percent (195 companies) of the companies that responded said that more than 80 of their directors and executive officers understood the meaning of biodiversity. In addition, 37.4% of companies indicated that they include information on biodiversity in their "management policies, strategies, plans, etc." and 71% of companies indicated that they include information on biodiversity in their sustainability and environmental policies. Their survey also asked whether they had assessed how much their value chain relies on biodiversity. Only 10% of companies have conducted such an assessment, but 48% have indicated that they are considering it. The TNFD uses a LEAP framework (Locate, Evaluate, Assess, Prepare). Of these, it is indicated that a relatively large number of companies have conducted the identification of biodiversity impact and dependence spots (L1), evaluation of biodiversity impact (E2), and identification of biodiversity-related risks and opportunities (A1). As biodiversity risks, it has been pointed out that the ecosystem balance will be disrupted, that it will become impossible to manufacture and conduct research due to the unavailability of raw materials derived from living organisms, and that environmental conservation costs will increase.

Keidanren also reports various activities by member companies that contribute to preserving biodiversity (Keidanren Committee on Nature Conservation, 2023a, 2023b). KDDI, a telecommunications company, installs base stations and cables in a wide area. In doing so, they take measures such as avoiding land modification in areas rich in nature, such as protected areas, natural heritage sites, and national parks and using paints that do not contain harmful substances. In the sea, they promote route designs that avoid coral reefs, select landing points that reduce modification, and miniaturize cables by improving transmission capacity. JFE

Holdings, which manufactures iron, non-ferrous metals, and metal products, uses steel slag to create a base for marine organisms to attach to, thereby improving marine life's environment and restoring marine organisms' ability to purify water. Shionogi & Co., a pharmaceutical company, maintains and manages over 1,000 species of plants in its botanical garden, including 76 endangered species. Japan Airlines has signed the "Buckingham Palace Declaration of the Special Committee on Transport for the Wildlife Conservation League," which aims to reduce the illegal wildlife trade. Suzuki, a manufacturer of transportation machinery and equipment, has developed a device for collecting microplastics from water and is contributing to the collection of microplastics near the water's surface. The real estate company Mori Building research to verify the effects of its projects on the environment. Specifically, they are conducting thermal imaging surveys, monitoring surveys of green coverage, and monitoring surveys of birds before and after their projects. The chemical industry company Toyo Ink SC Holdings Co., Ltd. uses the IBAT biodiversity assessment tool to check whether there are any important areas of biodiversity within a 2.5km radius of their production bases. The biotechnology company Kyowa Hakko Kirin has set up a committee within the company to ensure compliance with the Cartagena Protocol on Biosafety, a law concerning the conservation and sustainable use of biological diversity through regulations on the use of living modified organisms. In addition, they are managing to prevent genetically modified organisms from spreading outside their institutions and prevent employees from coming into contact with them inadvertently. The chemical company Daiichi Sankyo Co., Ltd. calculates and monitors its ecological footprint to assess its business activities' environmental impact.

Overall, our literature research shows that world-wide research on biodiversity risks and firm effects has begun to emerge in recent years. There is a call for more research on biodiversity finance. Current literature focuses on firms in the U.S or European countries, there are few research about Asian countries. To fill the research gap, we examine the impact of

biodiversity loss and biodiversity dependency on firm performance in Japan context. Our research is differentiated current literature in two ways. First, our research uses the latest firm-level biodiversity panel data of Japanese listed firms to exam the impact of biodiversity on firms' value. As documented in Subsection 2.2, Japan is different from the countries examined by the literature in terms of diverse biodiversity with the high rates of endemism; well-rooted legal and institutional system, and corporate cultures toward biodiversity conservation, which will provide new findings to the related literature. Second, we not only focus on the impact but also examined the mechanism and the moderating roles of firms' characteristics. Our research illustrates detailed case studies on how companies manage these issues in their own business activities. The findings using Japanese data can be a good reference to management, investors and policy makers of the countries with similar institutional and governance characteristics.

3. Data and methodology

3.1. Data collection

We use several well-known databases in Japan to construct our research sample. Data on firm-level biodiversity is obtained from Iceberg Data Lab. This database has been used in several international publication (Garel et al., 2023). Information on firms and boards of directors is from the Director Database of Toyo Keizai (Directory of Directors) provided by Toyo Keizai Inc. Information on firm corporate governance and financial performance is from the Nikkei NEEDS Corporate Governance Evaluation System (CGES) provided by Nikkei Inc. and the Corporate Financial Databank supplied by the Development Bank of Japan. We exclude financial firms from our sample as these employ different performance measurement ratios to firms in other industries. Supplementary data sources include Nikkei Value Search, government reports, and the individual company homepages. Using these data sources, we built

an unbalanced panel data for all non-financial listed firms in Japan from 2018 to 2023, of about 1,480 firm-year observations.

Our research originality of the research lies on the biodiversity variables developed by Iceberg Data Lab. We explain in details the variable creation and meaning below.

3.1.1 Corporate Biodiversity Footprint (CBF)

The Corporate Biodiversity Footprint is a measuring tool of biodiversity footprint. Footprints in an environmental context, are measures of humans' direct and indirect impact on the natural world. The impact of a commodity, company, person or community on global biodiversity, measured in terms of biodiversity change as a result of production and consumption of particular goods and services. By definition, *CBF is designed to assess the annual impact of activities of corporates, financial institutions, real assets and sovereign entities on global and local biodiversity*. This appraisal is based on the impact generated from the products purchased or sold by companies calculated throughout their value chain.

The CBF methodology uses the Mean Species Abundance (MSA) metric to quantify Biodiversity impact. MSA is a biodiversity metric expressing the average relative abundance of native species in an ecosystem compared to their abundance in an ecosystem undisturbed by human activities and pressures. This indicator is based on species abundance, which is the number of individuals per species, and therefore measures the conservation status of an ecosystem in relation to its original state. For instance, an area with an MSA of 0% will have completely lost its original biodiversity (or will be exclusively colonised by invasive species) whereas an MSA of 100% reflects a level of biodiversity, equal to an original, undisturbed ecosystem. This metric is endorsed by the scientific community and multilateral organizations (e.g., CBD, IPBES, and IPCC) and recommended by the UN.

CBF is an absolute metric and calculated by the four-step approach mentioned in IDL methodological guide[11]:

1. To use its physical Input/Output model Wunderpus mapping the flows and purchases of goods and services on which depend its activity and allocate the company's product flows by European 16 sector. Data is from company reports and Factset.
2. To assess and calculate each environmental pressures of the company, which will be based on its activity's mix;
3. To translate all the pressures through pressure-impact damage functions (based on GLOBIOmodel[12]) into a same biodiversity impact unit, which is Km 2. MSA;
4. To aggregate the different impacts in an overall absolute impact.

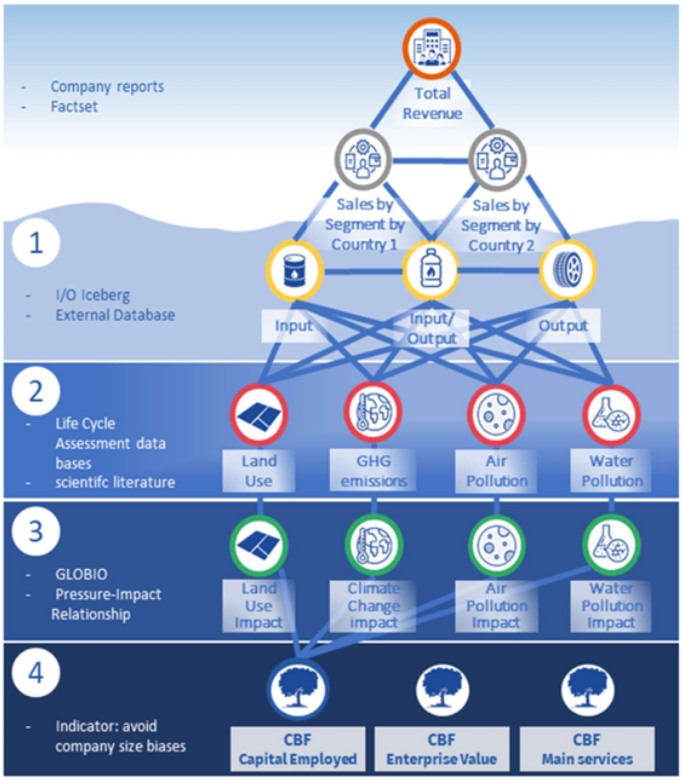
   Figure 1 below illustrate how data is processed from the modelling of commodities based on revenues over applying pressures to the calculation of the impact.

As shown in Figure 1, CBF aggregates the biodiversity loss caused by a firm's annual activities related to land use, greenhouse gas (GHG) emissions, water pollution, and air pollution. CBF is expressed in the Km².MSA unit and corresponds to a negative impact (footprint) on biodiversity (i.e. the difference between an initial and a final state of biodiversity). This unit makes the score result easily understandable by non-experts.

Figure 1: Data processing and modelling from financial data and company reports to environmental indicators. (Source: IDL)

[11] Microsoft Word - CBF client methodological guide March 23.docx

[12] The GLOBIO model expresses the response of ecosystems to anthropogenic pressures. This response is evaluated from a set of quantitative relationships and is expressed in Mean Species Abundance-MSA for each of the pressures taken into account by the model. These pressures are climate change, atmospheric nitrogen deposition, land use, infrastructure and human encroachment. The MSA values per pressure are calculated on the basis of empirical data allowing to compare the species observed in disturbed and undisturbed reference habitats. All in all, the GLOBIO model covers six taxonomic groups: amphibians, birds, mammals, terrestrial invertebrates, reptiles, and vascular plants.



For example, -1 Km².MSA corresponds to the biodiversity value contained in 1Km² of tropical pristine forest undisturbed by human activities. A CBF of -100km2.MSA also means that 10% of the original biodiversity has been lost in an area of 1,000km2, or that a proportionally smaller amount of biodiversity, 5%, has been lost in an area of 2,000km2. In 2022, CBF value of Toyota Motor Corporation is -5,355.34 km2.MSA, which means Toyota has caused the loss of 10% of the original biodiversity in an area of 53,553km2 or 5% biodiversity loss in an area of 107,106km2. Toyota's CBF is much higher than that of Honda Motor Ltd (-2,572.20 km2.MSA), Nissan Motor Ltd (-1,554.08 km2.MSA) or Mitsubishi Motors Corporation (-493.05 km2.MSA).

It is noted that CBF quantifies not only the direct impact of a firm, but also the biodiversity loss along the entire value chain. The CBF contains scope 1, 2, and 3 components, whereby scope 1 measures the environmental pressure of the firm's direct activities, such as the area artificialized or occupied due to its business activity; scope 2 measures the pressures induced by the purchase of electricity, heat, and cooling; and scope 3 measures all indirect

pressures (i.e., products sold or purchased, or investments made). Back to the example of Toyota Motor Corporation, CBF of Toyota mainly comes from the land use in its upstream value chain and the use phase of its sold vehicles. For the upstream value chain, passenger cars have a significant environmental footprint even before running due to the high amount of raw materials needed to manufacture a car (metals, rubber, plastic, glass, fiber, leather...etc). For the use phase of its sold vehicles, as most of the company's cars are powered by fossil fuels (diesel, gasoline, or LPG) they emit a lot of GHG and air pollutants (Nox and Sox) during their lifetime.

In this research, for empirical analyses, we employ eight CBF variables, namely *CBF*, *CBF scope 1*, *CBF scope 2*, *CBF scope 3*, *CBF GHG*, *CBF land u*se, *CBF water pollution*, *and CBF air pollution*. The definition of these variables can be found in the Appendix 1.

3.1.2. Biodiversity Dependency Scores

Apart from CBF, we use another biodiversity-related variable named Biodiversity Dependency Scores also delivered by Iceberg Data Lab. This variable expresses the severity of the corporate dependency on ecosystem services – the greater the dependency the greater the incurring risks, ranging between 0% and 100%. 0% means lowest dependency and therefore lowest risk while 100% means the highest dependency and therefore highest risk. This measurement aggregates from three sub-scores which corresponding to provisioning, regulating and cultural services.

Figure 2: Ecosystem services covered by IDL’s Biodiversity Dependency Scores

Provisioning	Regulating	Cultural
Fibers and other materials	Soil Quality	Spiritual Experience And Sense Of Place
Genetic material	Water Flow Maintenance	Information For Cognitive Development
Animal Based Energy	Water Quality	Inspiration For Culture Art Design
Surface Water	Ventilation	Recreation And Tourism
Ground Water	Maintain Nursery Habitats	Aesthetic Information
	Bio Remediation	
	Filtration	
	Dilution By Atmosphere And Ecosystems	
	Mediation Of Sensory Impacts	
	Buffering And Attenuation Of Mass Flows	
	Pest Control	
	Disease Control	
	Pollination	
	Mass Stabilization And Erosion Control	
	Climate Regulation	
	Flood And Storm Protection	

(Source: IDL)

In brief, Dependency Scores assess the nature related dependencies of businesses and financial institutions through dependency on ecosystem services. Figure 2 below illustrates 26 ecosystem services used by IDL. They are categorized as provisioning, regulating, and cultural services. Definitions of 26 ecosystem services are provided in Appendix 2. Dependency scores on Provisioning and Regulating ecosystem services are measured by ENCORE[13]. Each sector's potential dependency on ecosystem services and potential impacts on natural capital assets are assessed using sector research and expert interviews. As for cultural ecosystem services, IDL calculated the scores themselves based on sector research and expert interviews as well. In this research, we employ four dependency scores, namely *Dependency Value*, *Cultural*

[13] ENCORE (Exploring Natural Capital Opportunities, Risks and Exposure) is a tool that can help firms assess their dependencies and impacts at a portfolio level. Developed by the ENCORE partnership consisting of Global Canopy, UNEP FI and UNEP-WCMC, ENCORE covers the entire economy and guides organisations through the early stages of their nature-positive journey. It can help financial institutions take their first steps towards understanding their dependencies and impacts on nature. https://encorenature.org/en

Dependency Value, *Provisioning Dependency Value*, *Regulating Dependency Value*. The definition of these variables can be found in the Appendix

3.2. Hypotheses

With this study, we investigate the effects of biodiversity loss and corporate biodiversity dependency on firm value by using two key sets of biodiversity variables provided by Iceberg described in subsection 3.1.1 and 3.1.2. Firms' financial performance is proxy by ROA and ROE and firm value proxy by Tobin's Q.

We formulate our main research hypotheses as follows:

Hypothesis 1: Firms' CBF is negatively related to firms' performance.

Hypothesis 2: Firms' dependency to biodiversity is negatively related to firms' performance.

Our baseline panel data regressions are as follows:

$$ROA_{i,t} = \alpha + \beta_1 Dependency/CBF_{i,t} + \delta Controls_{i,t} + \varepsilon_{i,t}$$

$$ROE_{i,t} = \alpha + \beta_1 Dependency/CBF_{i,t} + \delta Controls_{i,t} + \varepsilon_{i,t}$$

$$TobinQ_{i,t} = \alpha + \beta_1 Dependency/CBF_{i,t} + \delta Controls_{i,t} + \varepsilon_{i,t}$$

Furthermore, to check the robustness of our results, we then make various sensitivity analyses with additional control variables to the baseline ones (governance and CSR variables), with lagged-1 values of biodiversity variables, with the distinction between firms manufacturing industries and non-manufacturing ones.

4. Descriptive statistics

4.1 CBF

Table 1 presents the summary statistics of the main variables used in the analysis. These are for an unbalanced panel data for 355 nonfinancial individual firms listed on several Japanese stock exchanges from 2018 to 2023. We have 200 firms for 2018, 233 firms for 2019, 346 firms for 2020, 349 firms for 2021, 311 firms for 2022. As for the year 2023, we received biodiversity data from IDL for 42 firms so far. Therefore, data of 2023 is not a full firm sample.

The first column lists the variable names. The mean value of CBF is 642.46km2.MSA, indicating that the average firm has a biodiversity impact corresponding to the complete loss of biodiversity over an area of 642.46 km2, which is higher than the average value of total 34 countries of 120.3km2 documented by Garel et al. (2023). Japan ranked 18th among 34 countries in term of CBF value adjusted by total assets (See Appendix 3 for details). However, the median value of CBF is 245.79km2.MSA, indicating that typically, Japanese firm has a biodiversity impact corresponding to the complete loss of biodiversity over an area of 245.79 km2, which is now closer to the median value of total 34 countries of 196.4km2. One explanation for the difference in CBF mean of Japanese firms compared to the cross-country value is the size of Japanese firms included in IDL database. The mean of total assets of our firms are significantly larger than that of firms reported by Kubo and Nguyen (2021), indicating that most firms in IDL database are large Japanese corporations.

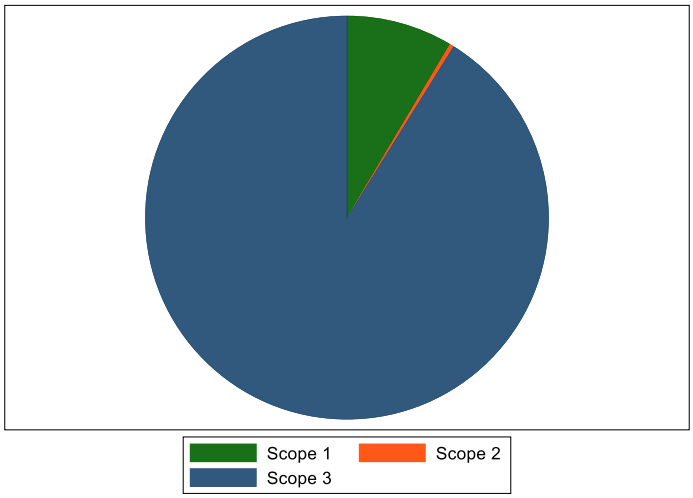
[INSERT TABLE 1 HERE]

When we decompose the CBF value based on Scope type, we find that CBF value are mainly made up by CBF Scope 3. CBF Scope 1 comes second while CBF Scope 2 is the smallest component of the total CBF. Figure 3 illustrates the decomposition of CBF in term of scope. Our finding somehow is similar to Garel et al. (2023) that Scope 3 dominates. By definition, CBF Scope 3 shows the biodiversity loss due to the firm's indirect activities (such as its products sold or investments made, or products purchased by the firm). Scope 3 dominates indicating that most large firms do not directly impact on the environment. This

metric measures the impact of a company's activities on biodiversity due to greenhouse gas emissions that occur outside of its direct control.

Indeed, CBF Scope 3 is compound of Scope 3 Upstream and Scope 3 Downstream. As shown in Table 1, the Scope 3 footprint are largely from activities upstream as mean and median CBF Scope 3 Upstream are both larger than CBF Scope 3 Downstream. CBF Scope 3 Upstream is calculated by multiplying the amount of greenhouse gases emitted by the company's upstream activities (ex. Provision of farmland or extraction of raw materials) by the biodiversity value of those emissions. CBF Scope 3 Downstream is calculated by multiplying the amount of greenhouse gases emitted by the company's products or services by the biodiversity value of those emissions. Both indicates that biodiversity loss occurs outside of firms' direct control.

Figure 3: Decomposition of the CBF by scope type



More importantly, we find that the CBF composition of Japanese firms are different from the cross-country sample. CBF Scope 3 makes up roughly 90%, Scope 1 makes up 7% while Scope 2 makes up roughly 3%. In the 34-country sample, Scope 3 contributes about 79% to the CBF value; Scope 1 15%; Scope 2 6% correspond. Comparing with other firms world-wide, we find that although total CBF of Japanese sample is larger than the world-wide average

but these firms do not directly impact on the environment that much. Their direct impact is smaller that the average world-wide value.

Similarly, we decompose the CBF into its four sources: Land use, GHG emissions, water pollution, and air pollution as shown in Figure 4. We find that the greatest impact on biodiversity loss is from land use, followed by water pollution, GHG, and air pollution. This order is different with the cross-country sample, where GHG emissions comes the second. Therefore, we suggest that Land use and Water pollution should be the focus on Japan in order to reduce biodiversity loss. The Japan 30by30 Roadmap, which aims to protect or conserve at least 30% of land and sea areas by 2030, is expected to contribute to solve this issue.

Figure 4: Decomposition of the CBF by sources of biodiversity loss

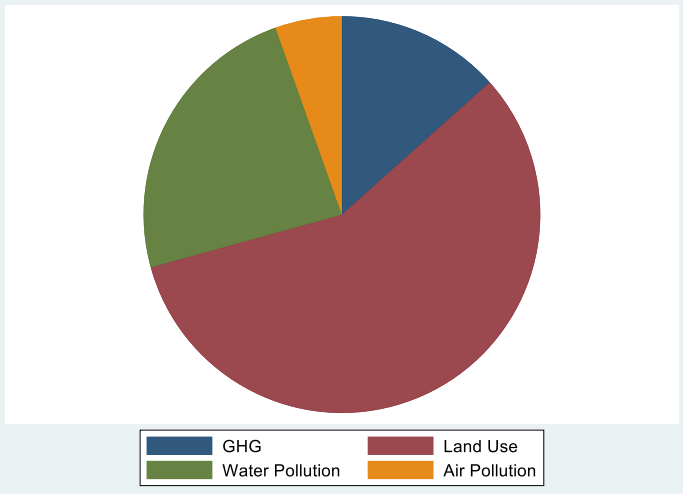
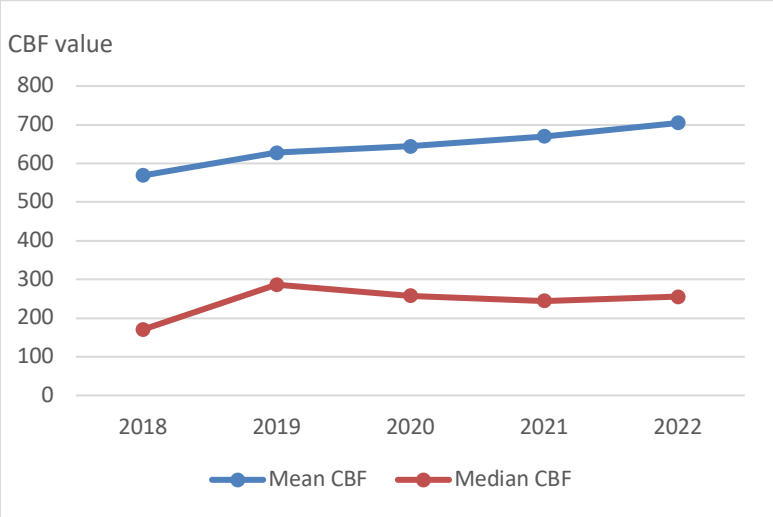


Figure 5 illustrates the yearly trend of CBF value from 2018 to 2022. Mean CBF increases gradually while median CBF started a small decline trend from 2019. In short, there is no large change in biodiversity loss caused by firms in our data sample.

Figure 5: CBF distribution by year (2018-2022)



4.2. Biodiversity dependency

Table 1 also present our second important biodiversity variable, Dependency score. The mean value of Dependency is 11.72%, indicating that on average, 11.72% of firms' business depends on the ecosystem services. Garel et al. (2023) did not tough on this variable, so we cannot make comparison. Among three components of the Dependency scores, value of Provisioning dependency is highest, of 19.76%. This indicates that Japanese firms depend most on the provisioning ecosystem services, including surface water, ground water, genetic material and animal-based energy (details can be found in Appendix 2). In addition, the Regulating dependency is also high, of 11.91%. This indicates that Japanese firms also face with the transition risks, stemming from regulations/policies introduced by regulators to mitigate biodiversity loss.

4.3. Other firm characteristics.

Regarding other firm characteristics, on average, and as shown in Table 1, boards in Japan have ten members in average, mostly aged directors having average age of 63. Outside directors make up a significant share of the boardroom, roughly 37%. In the same vein, most board members are male, with female directors accounting for only 10% of all board positions.

These firms have the institutional ownership ratio of 18% while the share of foreign shareholders is small.

To investigate whether there are differences in firm characteristics between firms with high biodiversity footprint and low ones, between firms with high biodiversity dependency and low ones, we carry out several univariate tests. First, we divided firms into two groups based on CBF value. High-CBF firms are one having CBF larger than the mean CBF of the whole sample while low-CBF firms are one having CBF equal or smaller than the mean CBF. Results of the univariate test between these two groups are shown in Panel A of Table 2a. Considering the result of both t-test and F-statistics, the two groups are not only different in CBF but also in various firm characteristics. Firm having large impact on biodiversity loss are bigger in size, larger, older and more diverse board, higher institutional ownership, more debt and poorer financial performance than firms having low impact on biodiversity loss.

[INSERT TABLE 2a HERE]

Second, we divided firms into two groups based on biodiversity dependency value. Highly-dependent firms are one having dependency value larger than the mean dependency score of the whole sample while smally-dependent firms are ones having dependency value equal or smaller than the mean dependency score. Results of the univariate test between these two groups are shown in Panel B of Table 2a. Firm having high dependency on biodiversity have older board, less debt, higher institutional ownership, less debt and poorer financial performance.

Overall, the univariate comparisons show that there are differences in firm characteristics between firms with high and low CBF, firms with high and low biodiversity dependency. In order to control for the possible biases resulted from these differences, we include control variables of firm size, board characteristics, leverage, and ownership structure in all regressions where applicable.

In addition, we investigate the impact of biodiversity based on sectors. We divided firms into two groups: manufacturing firms and nonmanufacturing firms using TSE industry code. The univariate comparison in Table 2 shows that manufacturing firms differ substantially. Firms in manufacturing industries have higher CBF, of 777.22 km2.MSA that that of firms in other industries (473.24 km2.MSA). Regarding biodiversity dependency, manufacturing firms have higher aggregated dependency score than that of other firms, 14.15% compared with 8.32%. Score breakup show that manufacturing firms depend largely on provisioning ecosystem services (28.31%).

[INSERT TABLE 2b HERE]

As TSE industry classification is different from the industry classification used by IDL. In order to compare with the results found by Garel et al. (2023), we rank the CBF across industries (Table 3) using the industry classification provided by IDL. Lower rank values indicate larger biodiversity footprints. The top five industries having highest CBF in Japan is Tobacco, Energy, Electrical Equipment, Paper and Forest, and Beverages. This order is different from the cross-country findings, in which Retail and Wholesale tops the rank, followed by Paper and Forest, Food, Asset Management and Oil and Gas.

[INSERT TABLE 3 HERE]

5. Empirical tests

5.1 CBF and firm performance.

In this subsection, we measure the effects of CBF on firm performance using OLS with robust standard errors clustered at the firm level and fixed effects regressions. The dependent variables are ROA, ROE and Tobin's Q. The independent variable of interest is the Ln(CBF). To avoid the effects of outliers, follow Garel et a. (2023), we winsored all CBF variables at the 2.5 percent and 97.5 percent levels. We also control for board and firm characteristics by

including board size, board age, outside director ratio, female director ratio, total assets (log form), leverage, foreign ownership ratio, and institutional ownership ratio as control variables. Following Adams (2016), we use firm fixed effects regression to address potential omitted variable bias caused by factors such as corporate culture and workplace practices.

Columns 1 and 2 in Table 4 present the OLS and fixed effects regression estimates of the effects of CBF on ROA. The coefficients for Ln(CBF) are positive and statistically significant in both the OLS and fixed effect regressions. Columns 3 and 4 in Table 4 provide the regression estimates of the effects of CBF on ROE. We find similar results to ROA in that the signs of the estimated coefficients are positive and significant in OLS regressions, but not FE regression. As for Tobin's Q, we find no relationship between CBF and this variable.

[INSERT TABLE 4 HERE]

The results in Table 4 thus indicate the positive impact of CBF on firms' operating performance measured by ROA. As found in Section 4, sources of CBF in Japan is largely from the devastation of land and water. We assume that these firms used extensively land and water for their business. The exploitation of the natural resources benefited firms' profit. These firms, in contrast, caused large biodiversity loss and damage the ecosystems.

5.2 Biodiversity dependency and firm performance.

In this subsection, we measure the effects of biodiversity dependency on firm performance using OLS with robust standard errors clustered at the firm level and fixed effects regressions. Similar to the previous section, the dependent variables are ROA, ROE and Tobin's Q. The independent variable of interest is the *Dependency Value* expressed in %. We also control for board and firm characteristics similarly to Table 4.

In all regressions, the coefficients for *Dependency Value* are negative in both the OLS and fixed effect regressions for all dependent variables. However, the coefficient is only statistically significant in the OLS regression for ROA, as shown in Column 1 in Table 5.

[INSERT TABLE 5 HERE]

The results in Table 5 thus indicate the negative impact of firms' biodiversity dependency on firms' operating performance measured by ROA. As found in Section 4, Japanese firms are largely dependent on provisioning ecosystem services such as ground water and surfaced water and regulating ecosystems. We assume that these firms used extensively provisioning ecosystem services for their business, especially manufacturing firms. The collapse of these ecosystems will damage firms' profit. These firms also face with the risks of intense policy and legal mandates relating to biodiversity conservations.

6. Addition analyses

In this section, we carry out further investigation on the relationship between biodiversity and firm value. First, we examine the interactions between two biodiversity variables. As found in Section 5, CBF has a positive relation with ROA in both OLS and FE regressions; CBF has a positive relation with ROE in OLS regression; firm biodiversity dependency has a negative with ROA in OLS regression. The findings are economically significant at the significance equal or larger than the 10% level. We find no relationship between biodiversity and market value. So far we examine the impact using CBF and dependency variables isolated. As there may have an interaction between these two biodiversity variables, there may be hiding relationships that aren't apparent when looking at these individual variables in isolation. To examine the interaction, we include both CBF and dependency variables in the OLS and FE regressions.

Table 6 present the OLS and fixed effects regression estimates of the effects of CBF and biodiversity on ROA, ROE and Tobin's Q. Columns 1 and 2 provide the regression estimates of the effects of CBF and dependency on ROA The coefficients for *Ln(CBF)* are positive and statistically significant in both the OLS and fixed effect regressions while the

coefficients for *Dependency Value* are negative and statistically significant in the OLS regression only. We find these results similar in coefficient signs, yet the magnitudes of coefficients are higher compared to those in Table 4 and Table 5. The statistics significance is stronger for *Dependency Value* variable. Columns 3 and 4 provide the regression estimates of the effects of CBF and dependency on ROE. We find several new results. The signs of the estimated coefficients for *Ln(CBF)* are positive and significant in both OLS and FE regressions. As for *Dependency Value*, the coefficient is negative and statistically significant at 10% level in the OLS regression. Columns 5 and 6 provide the regression estimates of the effects of CBF and dependency on Tobin's Q. Similar to the findings from Section 5, we find no relationship between CBF and biodiversity dependency and Tobin's Q.

[INSERT TABLE 6 HERE]

In short, we identify the positive interactions between CBF and biodiversity dependency variables, that the effects of biodiversity on firm accounting performance are stronger when we include these two variables together in the OLS and FE regressions.

7. Conclusion

This research investigates the relationship between biodiversity and firm value, using data of Japanese listed firms. We find that Japanese firms have large CBF caused by land use and water pollution. Corporate biodiversity footprint has a positive relation with ROA, indicating that firm operation benefits from natural resource exploitation. We also examine the effects of Corporate Biodiversity Dependency on firms' financial performance and find a negative relation with ROA. The collapse of the ecosystems together with increased regulations will damage firms' operating profit. Therefore, firms need to conserve the biodiversity in order to sustain their business in the long-term.

References

Adler, R., Mansi, M., Pandey, R. 2018. Biodiversity and threatened species reporting by the top Fortune Global companies. *Accounting, Auditing & Accountability Journal*, 31(3), 787–825. https://doi.org/10.1108/AAAJ-03-2016-2490

Ahmad, M. F., & Karpuz, A. (2024). Beyond climate change risk: Biodiversity and corporate cash holdings. Economics Letters, 236. https://doi.org/10.1016/j.econlet.2024.111608

Ai, M., Luo, F., Bu, Y. 2024. Green innovation and corporate financial performance: Insights from operating risks. *Journal of Cleaner Production*, 456, 142353.

Atkins, J., & Atkins, B. (2018). Around the world in 80 species. Milton: Routledge.

Aydoğmuş, M., Gülay, G., Ergun, K. 2022. Impact of ESG performance on firm value and profitability. *Borsa Istanbul Review*, 22, S119-S127.

Bach, T. N., Hoang, K., Le, T. 2024. Biodiversity risk and firm performance: Evidence from U.S. firms. *Business Strategy and the Environment*, In Press.

Bebbington, J., Unerman, J. 2018. Achieving the United Nations sustainable development goals. *Accounting, Auditing & Accountability Journal*, 31(1), 2–24. https://doi.org/10.1108/AAAJ-05-2017-2929

Bolton, P., Kacperczyk, M. 2021. Do investors care about carbon risk? *Journal of Financial Economics*, 142(2), 517-549.

Chen, S., Shen, W., Qiu, Z., Liu, R., Mardani, A. 2023. Who are the green entrepreneurs in China? The relationship between entrepreneurs' characteristics, green entrepreneurship orientation, and corporate financial performance. *Journal of Business Research*, 165, 113960.

Chen, Z., Xie, G. 2022. ESG disclosure and financial performance: Moderating role of ESG investors. *International Review of Financial Analysis*, 83, 102291.

Cheong, C. S., Gao, S., Lun, P., Mihaylov, G., & Zurbruegg, R. (2024). Biodiversity and the performance of tourism firms. Annals of Tourism Research, 109. https://doi.org/10.1016/j.annals.2024.103842

Coqueret, G., Giroux, T., Zerbib, O.D. 2025. The biodiversity premium. *Ecological Economics*, 228, 108435.

Drobetz, W., El Ghoul, S., Fu, Z., Guedhami, O. 2024. Institutional investors and corporate environmental costs: The roles of investment horizon and investor origin. *European Financial Management*, 30(2), 727-769.

Dyck, A., Lins, K. V., Roth, L., & Wagner, H. F. (2019). Do institutional investors drive corporate social responsibility? International evidence. *Journal of Financial Economics*, 131(3), 693-714.

Eichholtz, P., Holtermans, R., Kok, N., Yönder, E. 2019. Environmental performance and the cost of debt: Evidence from commercial mortgages and REIT bonds. *Journal of Banking & Finance*, 102, 19-32.

Fatemi, A., Glaum, M., Kaiser, S. 2018. ESG performance and firm value: The moderating role of disclosure. *Global Finance Journal*, 38, 45-64.

Finance for Biodiversity Foundation. 2023. *Top 10 biodiversity-impact ranking of company industries*. Reported by the European Commission with the following link: https://knowledge4policy.ec.europa.eu/publication/top-10-biodiversity-impact-ranking-company-industries_en

Garel, A., Romec, A., Sautner, Z., Wagner, A.F. 2024. Do investors care about biodiversity? *Review of Finance*, 28(4), 1151-1186.

Gao, N., Jiang, W., Jin, J. 2024. Why do investors exhibit varied reactions to ESG incidents reported by U.S. firms world-wide? *Journal of International Financial Markets, Institutions and Money*, 91, 101906.

Ginglinger, E., Moreau, Q. 2023. Climate risk and capital structure. *Management Science*, 69(12), 7492-7516.

Griffin, P.A., Lont, D.H., Lubberink, M.J.P. 2024. The effects of extreme high temperature spells on financial performance. *The British Accounting Review*, 101383.

Hassan, A., Roberts, L., Atkins, J. 2020. Exploring factors relating to extinction disclosures: What motivates companies to report on biodiversity and species protection? *Business Strategy and the Environment*, 29(3), 1419-1436.

Hassan, A., Roberts, L., Rodger, K. 2022. Corporate accountability for biodiversity and species extinction: Evidence from organizations reporting on their impact on nature. *Business Strategy and the Environment*, 31(1), 326-352.

Hoang, T.H.V., Pham, L., Nguyen, T.T.P. 2023. Does country sustainability improve firm ESG reporting transparency? The moderating role of firm industry and CSR engagement. *Economic Modelling*, 125, 106351.

Holsinger, K. E. 2001. The conservation of wild plant species in seed banks: Attention to both taxonomic coverage and population biology will improve the role of seed banks as conservation tools. *BioScience*, 51(3), 256–257. https://doi.org/10.1641/0006-3568(2001)051[0256:BITUS]2.0.CO;2

Hudson, R. 2024. Biodiversity and risk in the financial sector. *Journal of Sustainable Finance and Accounting*, 2, 100009.

Kim, I., Wan, H., Wang, B., Yang, T. 2019. Institutional investors and corporate environmental, social, and governance policies: Evidence from toxics release data. *Management Science*, 65(10), 4901-4926.

Krueger, P, Sautner, Z, Starks, L.T. 2020. The importance of climate risks for institutional investors. *The Review of Financial Studies*, 33(3), 1067–1111.

Li, Y., Gong, M., Zhang, X.Y., Koh, L. 2018. The impact of environmental, social, and governance disclosure on firm value: The role of CEO power. *The British Accounting Review*, 50(1), 60-75.

Li, Y., Liu, X., Canil, J., & Cheong, C. S. (2025). Biodiversity risk and firm efficiency. Finance Research Letters, 71. https://doi.org/10.1016/j.frl.2024.106414

Liang, C., Yang, J., Shen, L., Dong, D. 2024. The role of biodiversity risk in stock price crashes. *Finance Research Letters*, 67A, 105856.

Lin, Y. E., Li, Y. W., Cheng, T. Y., Lam, K. 2021. Corporate social responsibility and investment efficiency: Does business strategy matter? *International Review of Financial Analysis*, 73, 101585.

Liu, J., Xiong, X., Gao, Y., Zhang, J. 2022. The impact of institutional investors on ESG: Evidence from China. *Accounting & Finance*, 63(52), 2801-2826.

Liu, L., Feng, A., Liu, M. 2024. The effect of green innovation on corporate financial performance: Does quality matter? *Finance Research Letters*, 62B, 105255.

Ma, F., Wu, H., Zeng, Q. 2024. Biodiversity and stock returns. *International Review of Financial Analysis*, 95A, 103386.

Marco-Fondevila, M., Alvarez-Etxeberria, I. 2023. Trends in private sector engagement with biodiversity: EU listed companies' disclosure and indicators. *Ecological Economics*, 210, 107864.

Mushafiq, M., Prusak, B., Markiewicz, M. 2023. Corporate social responsibility and forward default mediated by financial performance and goodwill. *Journal of Cleaner Production*, 428, 139396.

Naeem, N., Cankaya, S., Bildik, R. 2022. Does ESG performance affect the financial performance of environmentally sensitive industries? A comparison between emerging and developed markets. *Borsa Istanbul Review*, 22, S128-S140.

NatureServe. 2023. Biodiversity in Focus: United States Edition. NatureServe, Arlington, VA.

Pham, H.S.T., Tran, H.T. 2020. CSR disclosure and firm performance: The mediating role of corporate reputation and moderating role of CEO integrity. *Journal of Business Research*, 120, 127-136.

Qiu, Y., Shaukat, A., Tharyan, R. 2016. Environmental and social disclosures: Link with corporate financial performance. *The British Accounting Review*, 48(1), 102-116.

Qureshi, M. A., Kirkerud, S., Theresa, K., Ahsan, T. 2020. The impact of sustainability (environmental, social, and governance) disclosure and board diversity on firm value: The moderating role of industry sensitivity. *Business Strategy and the Environment*, 29(3), 1199-1214.

Rahat, B., Nguyen, P. 2023. Does ESG performance impact credit portfolios? Evidence from lending to mineral resource firms in emerging markets. *Resources Policy*, 85B, 104052.

Tian, G., Wang, K.T., Wu, Y. 2023. Does the market value the green credit performance of banks? Evidence from bank loan announcements. *The British Accounting Review*, 101282.

Tsang, A., Forst, T., Cao, H. 2023. Environmental, social, and governance (ESG) disclosure: A literature review. *The British Accounting Review*, 56(1), 101149.
Tzouvanas, P., Kizys, R., Chatziantoniou, I., Sagitova, R. 2020. Environmental and financial performance in the European manufacturing sector: An analysis of extreme tail dependency. *The British Accounting Review*, 52(6), 100863.
Veprauskaité, E., Adams, M. 2013. Do powerful chief executives influence the financial performance of UK firms? *The British Accounting Review*, 45(3), 229-241.
Wong, J. B., Zhang, Q. 2022. Stock market reactions to adverse ESG disclosure via media channels. *The British Accounting Review*, 54(1), 101045.
Xin, W., Grant, L., Groom, B., Zhang, C. 2023. *Biodiversity confusion: The impact of ESG biodiversity ratings on asset prices*. Available at SSRN 4540722.
Berrang-Ford, L., Biesbroek, R., Ford, J.D., Lesnikowski, A., Tanabe, A., Wang, F.M., Chen, C., Hsu, A., Hellmann, J.J., Pringle, P. and Grecequet, M., 2019. Tracking global climate change adaptation among governments. Nature Climate Change, 9(6), pp.440-449.
BBC News. 2023. Climate Change Committee says UK no longer a world leader. Available at: https://www.bbc.co.uk/news/science-environment-66032607
Barber, B.M., Morse A. and Yasuda A. 2021. Impact investing. Journal of Financial Economics, 139, 162-185.
Bolton, P. and Kacperczyk, M., 2021. Do investors care about carbon risk? Journal of financial economics, 142(2), pp.517-549.
Climate Change Committee (CCC). 2023. Progress report to parliament. Available at: https://www.theccc.org.uk/publication/2023-progress-report-to-parliament/
Huang, H.H., Kerstein, J. and Wang, C., 2018. The impact of climate risk on firm performance and financing choices: An international comparison. Journal of International Business Studies, 49, pp.633-656.
Ilhan, E., Sautner, Z. and Vilkov, G., 2021. Carbon tail risk. The Review of Financial Studies, 34(3), pp.1540-1571.
International Panel on Climate Change (IPCC) Special Report. 2018. Global Warming of 1.5°C. Available at: https://www.ipcc.ch/2018/10/08/summary-for-policymakers-of-ipcc-special-report-on-global-warming-of-1-5c-approved-by-governments/
IPCC AR6 Synthesis report. 2023. Climate Change 2023. Available at: https://www.ipcc.ch/report/sixth-assessment-report-cycle/
Li, H., Liu, Y. and Xu, B., 2023. Does target country's climate risk matter in cross-border M&A? The evidence in the presence of geopolitical risk. Journal of Environmental Management, 344, p.118439.
Liu, Q., Trevisan, A.H., Yang, M. and Mascarenhas, J., 2022. A framework of digital technologies for the circular economy: Digital functions and mechanisms. Business Strategy and the Environment, 31(5), pp.2171-2192.
Gillan, S.L., Koch, A. and Starks, L.T., 2021. Firms and social responsibility: A review of ESG and CSR research in corporate finance. Journal of Corporate Finance, 66, p.101889.
Nguyen, D.D., Ongena, S., Qi, S. and Sila, V., 2022. Climate change risk and the cost of mortgage credit. Review of Finance, 26(6), pp.1509-1549.
Painter, M., 2020. An inconvenient cost: The effects of climate change on municipal bonds. Journal of Financial Economics, 135(2), pp.468-482.
Sangiorgi, I. and Schopohl, L., 2021. Explaining green bond issuance using survey evidence: Beyond the greenium. The British Accounting Review, 55(1), pp.101071.
Sautner, Z., Van Lent, L., Vilkov, G. and Zhang, R., 2023. Firm‐level climate change exposure. The Journal of Finance, 78(3), pp.1449-1498.
Shen, H., Yang, Q., Luo, L. and Huang, N., 2023. Market reactions to a cross-border carbon policy: Evidence from listed Chinese companies. The British Accounting Review, 55(1), pp.101116.
Starks, L.T. 2023. Presidential Address: Sustainable Finance and ESG Issues – Value versus Values. Journal of Finance, 74(8), 1837-1872.
Tangney, J.P., Stuewig, J. and Mashek, D.J., 2007. Moral emotions and moral behavior. Annual Review of Psychology, 58, pp.345-372.

Feng He, Longxuan Chen, Brian M. Lucey, Chinese corporate biodiversity exposure, Finance Research Letters, Volume 70, 2024, 106275, ISSN 1544-6123, https://doi.org/10.1016/j.frl.2024.106275.
Linhan Zhang, Qingliang Tang, Robin Hui Huang, 2021, Mind the Gap: Is Water Disclosure a Missing Component of Corporate Social Responsibility? The British Accounting Review,Volume 53, Issue 1,100940.
Faizul Haque, Michael John Jones (2020), European firms' corporate biodiversity disclosures and board gender diversity from 2002 to 2016, The British Accounting Review, Volume 52, Issue 2, 2020,100893.
Flammer, Caroline, Thomas Giroux, and Geoffrey Heal, "Biodiversity finance," Technical Report, National Bureau of Economic Research 2023.
Giglio, Stefano, Matteo Maggiori, Krishna Rao, Johannes Stroebel, and Andreas Weber, "Climate change and long-run discount rates: Evidence from real estate," The Review of Financial Studies, 2021, 34 (8), 3527–3571.
Giglio, Stefano, Theresa Kuchler, Johannes Stroebel, and Xuran Zeng, "Biodiversity Risk," Technical Report, National Bureau of Economic Research 2023.
Hoepner, Andreas GF, Johannes Klausmann, Markus Leippold, and Jordy Rillaerts, "Beyond climate: the impact of biodiversity, water, and pollution on the CDS term structure," Swiss Finance Institute Research Paper, 2023, (23-10).
Karolyi, G Andrew and John Tobin de la Puente, "Biodiversity finance: A call for research into financing nature," Financial Management, 2023.
Dasgupta, Partha, The economics of biodiversity: the Dasgupta review., Hm Treasury, 2021. https://www.gov.uk/government/publications/final-report-the-economics-of-biodiversity-the-dasgupta-review
Coqueret, G., Giroux, T., & Zerbib, O. D. 2025. The biodiversity premium. Ecological Economics, 228, 108435. https://doi.org/10.1016/j.ecolecon.2024.108435

Table 1: Summary statistics

Variables	Obs.	Mean	S.D.	Median
CBF	1,482	642.46	1,004.11	245.79
CBF scope 1	1,482	45.49	107.57	5.89

CBF scope 2	1,424	2.03	3.93	0.30
CBF scope 3	1,482	579.65	936.01	216.89
CBF scope 3 Upstream	1,482	385.41	632.33	137.151
CBF scope 3 Downstream	1,212	209	462.37	29.81
CBF GHG	1,482	79.14	171.36	12.91
CBF land use	1,482	338.80	618.12	93.37
CBF water pollution	1,482	140.93	337.89	11.53
CBF air pollution	1,482	32.10	68.20	6.51
Dependency Value	1,477	11.72	6.60	12.38
Cultural Dependency Value	1,477	3.09	6.25	0.00
Provisioning Dependency Value	1,477	19.76	13.51	23.95
Regulating Dependency Value	1,477	11.91	7.66	11.25
ROA	1,478	8.50	7.48	7.22
ROE	1,478	11.04	14.01	9.97
Tobin's Q	1,457	1.88	1.89	1.25
Total assets (million yen)	1,483	13,500,000	367,000,000	732.82
Leverage (%)	1,481	46.38	18.42	46.80
Outside director ratio (%)	1,480	37.45	12.69	36.40
Female director ratio (%)	1,483	10.78	7.97	9.10
Board size (n)	1,482	10.27	2.68	10.00
Board age average	1,483	63.03	3.98	63.00
Institutional ownership (%)	1,454	18.11	7.66	17.81
Foreign ownership ratio (%)	1,483	0.05	0.98	0.00

Notes: This table provides summary statistics for all variables. The sample consists of Japanese firms listed in IDL database from 2018 to 2023, whose primary industry is not financial services. Appendix 1 details the definitions of all variables

Table 2a: Summary statistics: Classification based the values of CBF and biodiversity dependency score

Panel A: Firm classification based on CBF value

Variables	High CBF			Low CBF			t-Statistic	Z-Statistic
	Obs.	Mean	Median	Obs.	Mean	Median		
CBF	393	1,898.56	1,384.86	1,089	189.16	134.10	43.85***	29.34***
ROA	394	6.75	6.14	1,084	9.14	7.84	5.47***	6.42***
ROE	394	10.60	9.38	1,084	11.20	10.15	0.72	1.72*
Tobin's Q	386	1.40	1.08	1,071	2.06	1.36	5.91***	7.41***
Total assets (million yen)	394	5,976,999	1,835,873	1,089	-18,400,000,000	526,526	0.85	16.28***
Leverage (%)	394	53.25	54.15	1,087	43.88	43.70	8.86***	8.65***
Board size (n)	394	10.69	10.50	1,088	10.11	10.00	3.67***	3.95***
Board age average	394	64.17	64.00	1,089	62.61	63.00	6.77***	6.19***
Outside director ratio (%)	394	39.66	37.50	1,086	36.64	35.50	4.07***	3.40***
Female director ratio (%)	394	11.55	10.25	1,089	10.51	9.10	2.23*	2.39**
Institutional ownership (%)	390	18.86	18.96	1,064	17.84	17.26	2.24*	2.79***
Foreign ownership ratio (%)	394	0.01	0.00	1,089	0.06	0.00	0.84	1.58

Panel B: Firm classification based on biodiversity dependency score

Variables	High dependency score			Low dependency score			t-Statistic	Z-Statistic
	Obs.	Mean	Median	Obs.	Mean	Median		
Biodiversity dependency score	779	17.18	16.99	698	5.64	4.83	68.75***	33.22***

ROA	780	7.46	6.83	698	9.67	7.99	5.72***	3.61***
ROE	780	9.88	9.25	698	12.34	11.29	3.38***	5.22***
Tobin's Q	766	1.56	1.18	691	2.24	1.40	7.03***	5.82***
Total assets (million yen)	785	-25,500,000,000	801,483	698	3,109,795	619,348	1.33	3.57***
Leverage (%)	783	45.41	46.20	698	47.46	48.25	2.14**	1.83*
Board size (n)	784	10.35	10.00	698	10.17	10.00	1.33	1.15
Board age average	785	63.64	64.00	698	62.33	63.00	6.43**	5.08***
Outside director ratio (%)	785	37.28	36.40	695	37.63	36.40	0.52	0.38
Female director ratio (%)	785	11.00	9.10	698	10.54	9.10	1.08	0.78
Institutional ownership (%)	776	19.03	19.02	678	17.07	16.44	4.92***	5.78***
Foreign ownership ratio (%)	785	0.01	0.00	698	0.09	0.00	1.61	2.13**

Notes: This table provides summary statistics for different firm groups. Panel A presents the hereto characteristics between firms with high CBF value and firms with low CBF. Panel B presents the hereto characteristics between firms with high biodiversity dependency score and firms with low dependency score. The sample consists of Japanese firms listed in IDL database from 2018 to 2023, whose primary industry is not financial services. Appendix 1 details the definitions of all variables. *, **, and *** denote significance at the 10%, 5%, and 1% level, respectively.

Table 2b: Summary statistics: Industry classification

Variables	All firms			Manufacturing firms			Non-manufacturing firms		
	Obs.	Mean	Median	Obs.	Mean	Median	Obs.	Mean	Median
CBF	1,482	642.46	245.79	825	777.22	310.47	657	473.24	180.89
CBF scope 1	1,482	45.49	5.89	825	38.25	6.78	657	54.59	3.81
CBF scope 2	1,424	2.03	0.3	798	2.63	0.66	626	1.27	0.20
CBF scope 3	1,482	579.65	216.89	825	719.47	291.66	657	404.08	110.12
CBF GHG	1,482	79.14	12.91	825	97.20	17.68	657	56.47	8.42
CBF land use	1,482	338.8	93.37	825	348.77	100.22	657	326.29	85.74
CBF water pollution	1,482	140.93	11.53	825	210.76	37.55	657	53.25	1.86
CBF air pollution	1,482	32.1	6.51	825	39.81	8.45	657	22.42	4.73
Dependency Value	1,477	11.72	12.38	820	14.45	15.72	657	8.32	4.82
Cultural Dependency Value	1,477	3.09	0	820	1.58	0.00	657	4.99	1.07
Provisioning Dependency Value	1,477	19.76	23.95	820	28.31	25.07	657	9.08	2.59
Regulating Dependency Value	1,477	11.91	11.25	820	14.15	15.77	657	9.12	4.84

Notes: This table provides summary statistics for all biodiversity-related variables. The sample consists of Japanese firms listed in IDL database from 2018 to 2023, whose primary industry is not financial services. Appendix 1 details the definitions of all variables.

Table 3. The CBF: ranking by industry

Ranking number	Industry	Mean CBF
1	Tobacco	2,081.62
2	Energy	2,043.56
3	Electrical Equipment	1,932.83
4	Paper and Forest	1,829.59
5	Beverages	1,557.40
6	Food	1,219.91
7	Pharmaceutical	1,075.25
8	Chemicals	993.22
9	Power	934.10
10	Metals & Mining	821.49
11	Automotive & Logistics	794.78
12	Textiles	704.63
13	Retail and Wholesale	692.02
14	Household goods	486.58
15	Electronics	344.22
16	Construction & Real Estate	343.75
17	Industrial Equipment	342.37
18	Telecommunications	293.18
19	Transportation	249.00
20	Asset Management	216.82
21	Healthcare	139.48
22	Oil & Gas	130.03
23	Building products	77.33
24	Software	36.69
25	Leisure	34.59
26	Media	33.55
27	Hotel and accommodations	15.83
28	Internet & Data	12.06
29	Services	11.37

Table 4
Effect of Corporate Biodiversity Footprint on firm performance: OLS and fixed effects regressions.

	(1)	(2)	(3)	(4)	(5)	(6)
Regression model	OLS	Fixed effects	OLS	Fixed effects	OLS	Fixed effects
Dependent variable	ROA	ROA	ROE	ROE	Tobin's Q	Tobin's Q
Ln (CBF)	0.544*	0.421**	1.019**	0.763	0.0202	0.00171
	(0.298)	(0.199)	(0.426)	(0.496)	(0.0215)	(0.00843)
Ln (total assets)	-1.111***	-4.625***	-1.096**	-8.079***	-0.150***	-0.111***
	(0.378)	(0.963)	(0.512)	(2.395)	(0.0306)	(0.0404)
Leverage	-0.184***	-0.278***	-0.0913**	-0.710***	-0.00848***	-0.00185
	(0.0203)	(0.0282)	(0.0353)	(0.0701)	(0.00180)	(0.00120)
Board size	-0.175*	-0.0582	-0.273*	-0.179	0.000712	0.00108
	(0.0929)	(0.0851)	(0.153)	(0.212)	(0.00738)	(0.00358)
Board age average	-0.284**	0.281***	-0.490**	0.610***	-0.0242***	0.00374
	(0.129)	(0.0807)	(0.212)	(0.201)	(0.00800)	(0.00341)
Outside director ratio	0.0256	-0.00475	0.0495	-0.00149	0.00419**	-0.000613
	(0.0272)	(0.0219)	(0.0476)	(0.0544)	(0.00199)	(0.000921)
Female director ratio	0.00703	0.0195	-0.0491	-0.00134	0.00567*	0.00119
	(0.0326)	(0.0297)	(0.0481)	(0.0739)	(0.00327)	(0.00125)
Institutional ownership	0.0194	-0.126***	-0.0571	-0.303**	-0.000795	-0.00287
	(0.0396)	(0.0485)	(0.0747)	(0.121)	(0.00321)	(0.00204)
Foreign ownership ratio	-0.0485	0.0296	-0.128	-0.139	-0.00244	0.00743
	(0.0917)	(0.113)	(0.158)	(0.281)	(0.00646)	(0.00472)
Constant	46.74***	67.41***	59.38***	119.2***	3.838***	1.855***
	(9.584)	(13.53)	(15.87)	(33.65)	(0.550)	(0.568)
Observations	1,446	1,446	1,446	1,446	1,422	1,422
R-squared	0.418	0.189	0.281	0.164	0.495	0.156
Industry dummies	YES	YES	YES	YES	YES	YES
Year dummies	YES	YES	YES	YES	YES	YES

Notes: The table provides OLS and fixed effects regression estimates of the effects of CBF on firm performance. The dependent variables as shown are ROA, ROE and Tobin's Q. The independent variable of interest is natural log value of CBF. All regressions control for board and firm characteristics and industry and year effects. Robust standard errors are in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% level, respectively.

Table 5
Effect of Corporate Biodiversity Dependency on firm performance: OLS and fixed effects regressions.

	(1)	(2)	(3)	(4)	(5)	(6)
Regression model	OLS	Fixed effects	OLS	Fixed effects	OLS	Fixed effects
Dependent variable	ROA	ROA	ROE	ROE	Tobin's Q	Tobin's Q
Dependency Value	-0.148**	-0.00579	-0.138	-0.0525	-0.00297	-0.00174
	(0.0609)	(0.0865)	(0.0959)	(0.215)	(0.00514)	(0.00362)
Ln (total assets)	-0.668**	-4.235***	-0.224	-7.396***	-0.134***	-0.109***
	(0.333)	(0.949)	(0.523)	(2.358)	(0.0243)	(0.0397)
Leverage	-0.177***	-0.275***	-0.0805**	-0.705***	-0.00828***	-0.00184
	(0.0186)	(0.0282)	(0.0335)	(0.0702)	(0.00176)	(0.00120)
Board size	-0.158*	-0.0608	-0.263*	-0.185	0.000905	0.00117
	(0.0882)	(0.0854)	(0.150)	(0.212)	(0.00722)	(0.00358)
Board age average	-0.267**	0.277***	-0.471**	0.599***	-0.0235***	0.00385
	(0.129)	(0.0811)	(0.212)	(0.202)	(0.00799)	(0.00342)
Outside director ratio	0.0201	-0.00526	0.0392	-0.00307	0.00415**	-0.000625
	(0.0282)	(0.0220)	(0.0498)	(0.0546)	(0.00200)	(0.000924)
Female director ratio	0.00696	0.0167	-0.0523	-0.00768	0.00557*	0.00116
	(0.0320)	(0.0298)	(0.0470)	(0.0741)	(0.00326)	(0.00125)
Institutional ownership	0.0135	-0.124**	-0.0642	-0.302**	-0.00103	-0.00280
	(0.0402)	(0.0487)	(0.0768)	(0.121)	(0.00326)	(0.00204)
Foreign ownership ratio	-0.0553	0.0412	-0.140	-0.118	-0.00261	0.00750
	(0.0898)	(0.113)	(0.153)	(0.281)	(0.00616)	(0.00472)
Constant	46.71***	64.55***	56.59***	115.1***	3.789***	1.845***
	(10.33)	(13.52)	(16.74)	(33.60)	(0.569)	(0.566)
Observations	1,442	1,442	1,442	1,442	1,418	1,418
R-squared	0.417	0.185	0.274	0.162	0.495	0.156
Industry dummies	YES	YES	YES	YES	YES	YES
Year dummies	YES	YES	YES	YES	YES	YES

Notes: The table provides OLS and fixed effects regression estimates of the effects of firms' biodiversity dependency on firm performance. The dependent variables as shown are ROA, ROE and Tobin's Q. The independent variable of interest is the biodiversity dependency value expressed in %. All regressions control for board and firm characteristics and industry and year effects. Robust standard errors are in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% level, respectively.

Table 6: Effect of CBF and Corporate Biodiversity Dependency on firm performance: OLS and fixed effects regressions.

	(1)	(2)	(3)	(4)	(5)	(6)
Regression model	OLS	Fixed effects	OLS	Fixed effects	OLS	Fixed effects
Dependent variable	ROA	ROA	ROE	ROE	Tobin's Q	Tobin's Q
Ln (CBF)	0.660**	0.463**	1.150***	0.856*	0.0229	0.00267
	(0.300)	(0.207)	(0.433)	(0.516)	(0.0222)	(0.00878)
Dependency Value	-0.188***	-0.0243	-0.208**	-0.0857	-0.00439	-0.00189
	(0.0628)	(0.0869)	(0.0969)	(0.216)	(0.00544)	(0.00365)
Ln (total assets)	-1.262***	-4.655***	-1.260**	-8.170***	-0.154***	-0.112***
	(0.373)	(0.966)	(0.509)	(2.404)	(0.0319)	(0.0405)
Leverage	-0.182***	-0.278***	-0.0896**	-0.711***	-0.00846***	-0.00187
	(0.0199)	(0.0282)	(0.0351)	(0.0702)	(0.00181)	(0.00120)
Board size	-0.146*	-0.0585	-0.242	-0.179	0.00125	0.00111
	(0.0873)	(0.0853)	(0.152)	(0.212)	(0.00721)	(0.00359)
Board age average	-0.268**	0.282***	-0.473**	0.609***	-0.0236***	0.00384
	(0.127)	(0.0811)	(0.209)	(0.202)	(0.00801)	(0.00342)
Outside director ratio	0.0258	-0.00482	0.0493	-0.00208	0.00435**	-0.000625
	(0.0271)	(0.0220)	(0.0484)	(0.0546)	(0.00199)	(0.000925)
Female director ratio	0.0118	0.0197	-0.0440	-0.00209	0.00575*	0.00117
	(0.0326)	(0.0298)	(0.0480)	(0.0742)	(0.00328)	(0.00126)
Institutional ownership	0.0148	-0.125**	-0.0616	-0.303**	-0.000994	-0.00285
	(0.0381)	(0.0487)	(0.0738)	(0.121)	(0.00320)	(0.00205)
Foreign ownership ratio	-0.0492	0.0284	-0.129	-0.142	-0.00241	0.00742
	(0.0915)	(0.113)	(0.158)	(0.281)	(0.00652)	(0.00473)
Observations	1,442	1,442	1,442	1,442	1,418	1,418
R-squared	0.417	0.185	0.274	0.162	0.495	0.156
Industry dummies	YES	YES	YES	YES	YES	YES
Year dummies	YES	YES	YES	YES	YES	YES

Notes: The table provides OLS and fixed effects regression estimates of the effects of firms' CBF and biodiversity dependency on firm performance. The dependent variables as shown are ROA, ROE and Tobin's Q. The independent variables of interest are CBF and the biodiversity dependency value expressed in %. All regressions control for board and firm characteristics and industry and year effects. Robust standard errors are in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% level, respectively.

Appendix 1: Variable definition and data sources

Variables	Definitions	Unit	Source
CBF-related variables	CBF-related variables are expressed in km2. MSA, which is equivalent to the pristine natural area destroyed by the firm's annual activities. MSA is a metric characterizing the level of biodiversity in an ecosystem. The original CBF metric is a negative number, corresponding to the degradation of biodiversity caused by the firm. We multiply this variable by –1 so that higher values indicate a more negative impact on bio diversity.		
CBF	Biodiversity loss caused by the firm's annual activities. It results from four environmental pressures: land use transformation, emission of GHGs, emission of nitro gen oxides, and release of toxic compounds into the environment.	km2.MSA	IDL
CBF Scope 1	Biodiversity loss due to the firm's direct activities (i.e., surface artificialized or occupied).	km2.MSA	IDL
CBF Scope 2	Biodiversity loss due to the firm's purchase of electricity, heat, and cooling.	km2.MSA	IDL
CBF Scope 3	Biodiversity loss due to the firm's indirect activities (such as its products sold or investments made, or products purchased by the firm).	km2.MSA	IDL
CBF Scope 3 Upstream	This metric measures the impact of a company's activities on biodiversity due to greenhouse gas emissions that occur outside of its direct control. *It is calculated by multiplying the amount of greenhouse gases emitted by the company's upstream activities by the biodiversity value of those emissions.*	km2.MSA	IDL
CBF Scope 3 Downstream	This metric measures the impact of a company's activities on biodiversity due to greenhouse gas emissions that occur outside of its direct control. It includes the impact of the company's products or services on the environment during their life cycle, use and disposal. *It is calculated by multiplying the amount of greenhouse gases emitted by the company's products or services by the biodiversity value of those emissions.*	km2.MSA	IDL
CBF GHG	Biodiversity loss due to the firm's GHG emissions. In addition to direct GHG emissions due to the firm's energy consumption, GHG emissions resulting from the electricity consumption and emissions of products purchased in the firm's upstream supply chain are taken into account.	km2.MSA	IDL

CBF land use	Biodiversity loss due to the firm's transformation of pristine land into agricultural land or artificialized areas. The firm's direct pressures on land use, such as its physical assets, buildings, or plantations, are factored in. The land use impact of the firm's upstream supply chain (i.e., purchased products) is also taken into account.	km2.MSA	IDL
CBF water pollution	Biodiversity loss due to the firm's release of toxic com pounds into the water. Release of substances due to the firm's direct activity (e.g., processing food or fertilizing crops) are taken into account, as well as those of the firm's upstream supply chain.	km2.MSA	IDL
CBF air pollution	Biodiversity loss due to the firm's release of nitrogen oxides (NOx) into the air. Direct pressures coming from the firm, such as NOx emissions arising from its fuel consumption, are taken into account, as are NOx emissions arising from the electricity consumption and emissions of products purchased in the firm's up stream supply chain.	km2.MSA	IDL
Firm biodiversity dependence variables			
Dependency Value	Weighted average of the three dependency scores, reflecting a company's dependence on ecosystem services.	%	IDL
Cultural Dependency Value	Dependency score of the company on the cultural ecosystem services.	%	IDL
Provisioning Dependency Value	Dependency score of the company on the provisioning ecosystem services.	%	IDL
Regulating Dependency Value	Dependency score of the company on the regulating ecosystem services.	%	IDL
Firm performance variables			
ROA (%)	Ratio of income before tax and interest to total assets.	%	CGES
ROE (%)	Ratio of income before tax and interest to total equity	%	CGES
Tobin's Q	Ratio of total assets and total debts in book value over total market value		CGES
Control variables			CGES
Board size	Number of board members		CGES
Board age average	Average age of board members		
Outside director ratio	Percent of outside director over total board members		CGES
Female director ratio	Percent of female director over total board members		CGES
Industry dummy	33 industries classified by Tokyo Stock Exchange		CGES

Total assets	Total consolidated assets	Million yen	CGES
Leverage (%)	Ratio of sum of short-term debt and long-term debt to total assets		CGES
Foreign ownership (%)	Ratio of foreign investors' ownership to total shares		CGES
Institutional ownership (%)	Percentage of company stock held by institutional investors		CGES

Appendix 2: Definitions of 26 ecosystem services

(Source: IDL)

Provisioning
Genetic material: genetic material from plants, algae, fungi, animals or organisms.
Animal-based energy: nutrition, materials or energy from grown in-situ aquaculture, reared or wild animals for direct use or processing.
Surface Water: surface water used for nutrition, materials or energy (freshwater or marine/coastal).
Ground Water: groundwater used for nutrition, materials or energy.
Regulating
Soil quality: regulation of physical, chemical, and biological conditions of the soil.
Water flow maintenance: hydrological cycle and water flow regulation (including flood control & coastal protection).
Water quality: regulation of the chemical condition of freshwaters, including salt water, by living processes.
Ventilation: regulation of temperature and humidity, including ventilation and transpiration, for people.
Maintain nursery habitats: Providing habitats for wild plants and animals that can be useful to us.
Bioremediation: Mediation of wastes or toxic substances of anthropogenic origin by living processes.
Filtration: Filtration/sequestration/storage/accumulation of wastes by microorganisms, algae, plants, and animals.
Dilution by atmosphere and ecosystems: mediation of waste, toxins and other nuisances by non-living processes, such as freshwater ecosystems or atmosphere.
Mediation of sensory impacts: mediation of nuisances of anthropogenic origin (ie. Smell reduction, noise attenuation and visual screening).
Buffering and attenuation of mass flows: regulation of baseline flows and extreme events such as the buffering and attenuation of mass movement.
Pest control: controlling invasive species and pests.
Disease control: controlling diseases.

Pollination: seed dispersal, pollination.
Mass stabilization and erosion control: control of erosion rates.
Climate regulation: regulation of the chemical composition of the atmosphere and the oceans as well as regulation of the temperature and humidity.
Flood and storm protection: Regulation of baseline flows and extreme events.
Cultural
Spiritual experience and sense of place: natural, abiotic characteristics of nature that enable spiritual, symbolic and other interactions and elements of living systems with symbolic meaning.
Information for cognitive development: characteristics of living systems that enable scientific investigation, the creation of traditional ecological knowledge or education and training.
Inspiration for culture art design: interacting intellectually, spiritually, and symbolically with the natural environment encompasses representative engagements.
Recreation and tourism: engaging physically, experientially, intellectually, and representationally with both the natural environment and its abiotic components facilitates holistic interactions and understanding.
Aesthetic information: characteristics of living systems that enable aesthetic experiences.

Appendix 3: Country ranking by Ln (CBF/total assets)
(documented from Garel et al., 2023)

