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Perspective Article

Is "Common But Differentiated Responsibilities" principle applicable in biodiversity? – Towards approaches for shared responsibilities based on updated capabilities and data

Hiroaki Tomoi [a,b], Takafumi Ohsawa [c], Jay Mar D. Quevedo [d], Ryo Kohsaka [d,*]

[a] London School of Hygiene & Tropical Medicine, London, United Kingdom
[b] School of Tropical Medicine and Global Health, Nagasaki University, Nagasaki, Japan
[c] Graduate School of Urban Environmental Sciences, Tokyo Metropolitan University, Hachiouji, Japan
[d] Graduate School of Agricultural and Life Sciences, the University of Tokyo, Japan

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ABSTRACT

The application of the "Common But Differentiated Responsibilities (and Respective Capabilities)" (CBDR-RC) principle in the field of biodiversity received criticisms due to the lack of scientific evidence and/or outdated categories which in turn resulted in a knowledge gap in its applicability in policy-making. Reflecting on this research gap, we reviewed existing relevant publications by quantifying and evaluating the responsibility of different countries under various categories (i.e., low-, middle-, and high-income) for biodiversity loss. As concrete indicators, we used the five direct drivers of biodiversity loss by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) to examine and identify biodiversity-related footprints and challenges, whereby the applicability of the CBDR principle was considered. Data on the national impact and positive contributions to global biodiversity were also encompassed, considering all available data from older periods as possible. The results showed that low-, middle-, and high-income countries contributed to biodiversity loss, with high-income countries as the largest contributor, indicating relatively high responsibility by developed countries. Meanwhile, developing (middle- and low-income) countries contributed about 44% of biodiversity loss. The results further indicated that the shared responsibility was not clear enough to be sorted out by a simple dichotomy between developed and developing countries and immediately applying the CBDR principle. Besides, the impact of global trade should be fairly attributed to consumer countries (frequently developed countries) and producer countries (developing countries). Moreover, the upward move in the income category in many countries in the last decades has not been fully reflected in discussions under the Convention on Biological Diversity. This means that the respective capabilities have not been considered in a timely manner in policy-making. As such, we propose non-binary "Differentiated But Shared Responsibilities (and Updated Capabilities)" (DBSR-UC) as a new concept, highlighting the need for incentives and burdens based on scientific evidence.

1. Introduction

The concept of "Common But Differentiated Responsibilities (CBDR)" was established as the seventh principle of the Rio Declaration adopted at the Earth Summit in 1992 (United Nations, 1992). The principle is defined as "states have common but differentiated responsibilities in view of the different contributions to global environmental degradation" (Pauw et al., 2014). The notion of CBDR and "Respective Capabilities" (CBDR-RC) is conceptualized based on international negotiations under the United Nations Framework Convention on Climate Change (UNFCCC) (Pauw et al., 2014). Under the convention, CBDR is put into practice by initially differentiating the responsibilities of parties based on the economic welfare of the countries; developed country parties such as the US, the EU, and Japan in Annex I and II, and the developed parties listed in Annex II shall provide new and additional financial resources for developing country parties.

Based on the UNFCCC classification, the Kyoto Protocol set legally binding quantified emission limitations for the Annex I parties while non-Annex I countries are not obligated to reduce their emissions. In contrast, the Paris Agreement adds the modifier "in the light of different

* Corresponding author at: Graduate School of Agricultural and Life Sciences, the University of Tokyo, 1-1-1 Yayoi Bunkyo-ku, Tokyo 113-8657, Japan.
E-mail address: kohsaka@hotmail.com (R. Kohsaka).

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national circumstances" to the CBDR principle. This means that the Paris Agreement interprets the CBDR-RC principle by distinguishing between "developed" and "developing" countries, instead of Annex I and non-Annex I countries (Pauw et al., 2014). Additionally, the Paris Agreement considers not only the binary classification of developed vs. developing countries but also the circumstances of individual countries (Rajamani, 2016). For instance, all countries can present their own reduction targets through their national climate action plans, commonly referred to as Nationally Determined Contributions (NDCs). Such a history implies that the CBDR principle has been a major point of contention in climate change negotiations (Pauw et al., 2014; Furlan and Mariano, 2021).

Applying the CBDR principle in the field of biodiversity has not been straightforward in comparison with climate negotiations, and there have been repeated conflicts between the so-called "North" and "South" regarding the application of the CBDR (or CBDR-RC) principle in the field of biodiversity since the 1990s (Humphreys, 1996). Recently, in the process of considering the post-2020 global targets for biodiversity conservation (post-2020 Global Biodiversity Framework [GBF]), there have been repeated claims that the CBDR principle should be included, *inter alia*, in finance-related targets (Linares 2022; SCBD, 2022a). Yet, the CBDR principle has often been discussed frequently from ethical and political views, and consequently, its application in describing biodiversity loss by individual countries has not been well established. Although ethical and political perspectives are vital, it is equally important that discussions are based on evidences in international policy processes, including the GBF, and in the subsequent negotiation phase of global targets (Burgass et al., 2021). Thus, in this study, we posed the following research question: Is the CBDR principle applicable to biodiversity? In addressing this question, we have two specific objectives. Firstly, to quantitively evaluate individual countries' contributions to the five direct drivers of biodiversity loss (land use change, overexploitation, climate change, pollution, and invasive alien species) presented by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (IPBES, 2019). Secondly, to quantitively examine these contributions in a collective manner, such as looking at countries' contributions to biodiversity loss encompassing all the drivers. The findings of this comprehensive review can be useful in identifying which countries have large contributions to biodiversity loss, what their responsibilities are, and how they can compensate for their negative impacts.

2. Methodology

2.1. Data gathering of relevant publications

The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) framework (Moher et al., 2009) was followed in this study for data gathering and processing (Supplementary Fig. 1). Using the advanced document search features of the Scopus database, we set our search of relevant publications within "Article Title, Abstract, Keywords (TITLE-ABS-KEY)", applying the following string of commands: ["biodiversity" AND "footprint" AND "global" AND ("contribution" OR "responsibility")]; ["pollution" AND "footprint" AND "global" AND ("contribution" OR "responsibility")]; and ["invasive species" AND "footprint" AND "global" AND ("contribution" OR "responsibility")]. The literature search was conducted in March 2022. In this step, we generated a total of 243 potential publications (Supplementary Fig. 1).

In the second and third stages, the generated publications were screened and checked for eligibility, respectively, based on the three criteria we set. Publications had (1) to cover at least one of the five direct drivers (land/sea use change, overexploitation, climate change, pollution, and invasive species) of biodiversity loss on a global basis (IPBES, 2019), (2) to examine a country's contribution to biodiversity loss, and (3) to be written in the English language. There were 227 publications excluded because they did not meet one or more of our inclusion criteria (Supplementary Fig. 1). Finally, a total (*n*) of 16 publications were included in our synthesis (Table 1).

Applying the same string of commands mentioned above, we did an additional round of document search using the Web of Science (WOS) database, which is frequently used in biodiversity-related systematic reviews (Mehring, 2020; Savilaasko, 2014; Fardila, 2017), to strengthen the comprehensiveness and coverage of our review (conducted on October 5th, 2022). Following the screening and eligibility check described above, nine articles were eventually included in this review and cross-checked with the existing dataset. As a result, no additional papers were identified; existing relevant publications were already included in the current table (Table 1). We incorporated this additional search in Supplementary Fig. 1.

2.2. Quantitative evaluation of individual country's contribution to biodiversity loss

Historically, drivers of biodiversity loss have been categorized in different ways by previous assessments. For instance, Sala et al. (2000) developed global scenarios of biodiversity in 2100 assuming a few possible changes (e.g., changes in climate, land use, nitrogen deposition, and atmospheric CO_2 concentration) to rank their impacts. Millennium Ecosystem Assessment by UNEP (United Nations Environment Programme, 2005) specified the following factors as key drivers changing ecosystems: increasing demands for ecosystem services, increasing pollution and waste, global trade and alien species, changing land use/cover, and changing climate. Furthermore, Salafsky et al. (2008) gave a unified classification of 11 direct threats to biodiversity, such as residential and commercial development, agriculture, and aquaculture. However, the global assessment conducted by IPBES (2019) attributed biodiversity loss to a few specific drivers by considering such previous assessments, and its result has given the most foundational frame in the Convention on Biological Diversity (CBD) discussions. Thus, our study adopted the five direct drivers identified by IPBES (2019) and their applicability is critically evaluated in the discussions.

Individual country's contribution to biodiversity loss was derived by multiplying their relative contribution rate by the global impact rate per driver (land-use change – 30%, overexploitation – 23%, climate change – 14%, pollution – 14% (water, excluding air and soil pollution), and invasive alien species – 11%) (IPBES, 2019). The remaining drivers that were not assigned to any of the above drivers accounted for about 8%. Air and soil pollution are included in the pollution but since footprint data were not available, we excluded them in our calculation and treated them as grey zone areas. Additionally, we did not consider synergies and trade-offs among the direct drivers, though theoretically, we could assume interactions amongst the drivers (see item 4 in Supporting Information). According to IPBES (2019), four indirect drivers are assumed behind the five direct drivers, such as rapid human population growth. Yet, to avoid overcomplicated results, we did not consider each country's contribution to such indirect drivers in our calculation.

We conducted a quantitative evaluation of 129 countries using the available data on Ecological Footprint (EF) and Biocapacity (see Supplementary Table 1 in Supporting Information). The former is an indicator of demand for ecosystems and can evaluate the dependency on ecosystem services while the latter is the absorption capacity of the footprint and production capacity of natural resources (Galli et al., 2012; Global Footprint Network, 2021). The difference between EF and Biocapacity can be used to quantify the extent of environmental burden beyond the capacity of nature. The 129 countries were categorized into three groups based on income categories (World Bank, 2021), namely: high-income (33 countries) as a high-income group, upper-middle-income (35 countries) as a middle-income group, and low- and lower-middle-income (61 countries) as a low-income group. High-income countries are defined as developed countries while the other two categories include all developing countries. The individual country's contribution rate per driver was calculated utilizing the following

Table 1
Relevant publications analyzed in this study.

Reference	Data and Data Period	Direct drivers to biodiversity loss (IPBES, 2019)				
		Land-use change	Over-exploitation	Climate change	Pollution	Invasive alien species
Mekonnen and Hoekstra (2011)	Water footprint (greywater footprint)				x	
Lenzen et al. (2012)	IUCN Red List: 2011, Threatened Birds of the World by BirdLife International: 2011, Eora MRIO database: 2011	x	x	x	x	
Nishijima et al. (2016)	IUCN Red List, Bilateral wood trade data, Global forest coverage loss data: 2000–2005		x			
Oita et al. (2016)	Eora MRIO database, FAOSTAT: 2015, IFA database: 2010–2010/11, IPCC Guidelines:2006				x	
Turbelin et al. (2017)	Global Invasive Species Database (GISD), CABI Invasive Species Compendium: 2016					x
Boden et al. (2017)	Historical energy statistics: 1751–1949, Energy statistics by the United Nations: 1950–2014			x		
Moran and Kanemoto (2017)	IUCN Red List: 2015, Threatened Birds of the World by BirdLife International: 2015, Eora MRIO database: 2011	x	x	x	x	
Verones et al. (2017)	Eora MRIO database: 2011, IUCN Red List, Nitrogen and Phosphorus data: 2011	x		x	x	
Wilting et al. (2017)	Mean Species Abundance, GHG emissions: 2007, FAOSTAT: 2007, Global Roads Inventory Project: 2015, GLOBIO: linearly interpolated between 2005 and 2010, WIOD and GTAP databases: 2007	x		x		
Weinzettel et al. (2018)	EXIOBASE and GTAP Database: 2007. FAOSTAT, Global potential net primary production:2007, Cropland and crop harvest patterns:2008	x				
Holland et al. (2019)	GTAP Database: 2010, IUCN Red List: 2011, Global Human Influence Index: 2005	x	x	x	x	
Marques et al. (2019)	EXIOBASE and FAOSTAT: 2000	x				
Weinzettel et al. (2019)	EXIOBASE and GTAP Database: 2007, FAOSTAT: 2018	x				
Hoang and Kanemoto (2021)	Eora MRIO database, Deforestation Drivers and annual forest loss data: 2001–2015, FAOSTAT	x	x			
Sarkodie (2021)	Ecological Footprint, Biocapacity, Carbon Footprint, Ecological Status by GFN: 1961–2016	x	x	x		
Sun et al. (2022)	FABIO and EXIOBASE: 1986 to 2013, Global Land System: 2005, HDI: no data	x				

methods.

2.2.1. Land-use change, overexploitation, and climate change

For the first three direct drivers – land-use change, overexploitation, and climate change drivers, the EF data (cropland footprint, grazing land footprint, forest products footprint, carbon footprint, fishing grounds footprint, and built-up land footprint) between 1961 and 2017 were applied.

Based on the assumption that crop and livestock production needs to alter the land, the contribution to land-use change was calculated using the Ecological Deficit (unit: global hectares [gha]), which is the difference between the sum of the footprints derived from cropland and grazing in the EF and the Biocapacity of each country. If the Biocapacity exceeded the sum of the footprints, which means that Ecological Reserve (the difference between EF and Biocapacity, when the Biocapacity > EF) was positive, the footprint derived from land-use change in the country was counted as zero.

The contribution of overexploitation to biodiversity loss was calculated using the difference between the sum of the footprints derived from forest production and fisheries and Biocapacity in the EF. This calculation assumed that forestry and fisheries were engaged in natural resource extraction, although forestry using planted forests and aquaculture are included. If Biocapacity exceeded the sum of the footprints, the footprint derived from forestry or fishery in the country was accounted as zero.

Climate change contribution was calculated using the carbon footprint in the EF. Since there were no country-level data on Biocapacity which accounted for the carbon footprint before 2001 (Jiang et al., 2021), the carbon footprint was regarded as the contribution of each country to climate change.

2.2.2. Pollution

Pollution includes air, water, and soil pollution, and ideally, all of these pollution types should be considered. However, the impact on biodiversity varies depending on the type of pollutant and the medium of pollution, and it is not realistic to make an exhaustive assessment of all combinations of them. Therefore, we made the following assumptions in our evaluation.

We assumed that the contribution to biodiversity loss is equal for each of the three pollution pathways. Therefore, the 14% contribution rate of pollution to biodiversity loss presented by the IPBES was divided equally among water, air, and soil pollution. However, when describing trends in the capacity of nature to regulate the environment, IPBES (2019) reported that water quality has become less controllable globally while trends in regulations of air quality and soil quality (formation, protection, and decontamination of soils) have been varied across regions over the last 50 years. Thus, among such different types of pollution, water pollution is most likely to have been beyond Biocapacity and affected biodiversity globally. Furthermore, as mentioned earlier, the contribution of air and soil pollution was not calculated due to the lack of available data. Therefore, focusing on water pollution, which is not captured by the EF (Kitzes and Wackernagel, 2009), we applied the grey water footprint (Mekonnen and Hoekstra, 2011) for the period 1996–2005. This indicator evaluates the pollutants load from wastewater by the amount of freshwater needed to dilute it.

2.2.3. Invasion of alien species

There were no available indicators and data to measure individual countries' impact on biodiversity caused by invasive alien species. Thus, we employed two proxies as complementary indicators. First, we used S_{Nat}, which is the number of species native to a country but considered as invasive alien species in other countries (Turbelin et al., 2017). Herein, S_{Nat} of overseas territories was incorporated into that of the mainland, as environmental responsibilities by invasive alien species from overseas territories may be attributed to colonial rulers (developed countries). Nonetheless, if we sum up all the numbers of S_{Nat} among all territories for the countries which have overseas territories, we may count the same species multiple times (particularly when such territories are geographically close to each other). Thus, for such countries, we summed up the maximum number of S_{Nat} across all territories from each subregion. We assumed that the maximum number of S_{Nat} may represent outflows of invasive species from each country's territories within each subregion. However, differences in impacts among invasive species were not reflected in the data on S_{Nat}.

Thus, in our second proxy indicator, we counted the number of the World's 100 Worst Invasive Alien Species originating from each country (S_{Worst}) listed by IUCN-ISSG (2013). To collect the data on source countries, we consulted the database of CAB International (2022) (most species) or IUCN-ISSG (2013) (a few species). Although worst invasive alien species are widely distributed across many countries, certain species have little to no information available from the source countries. Thus, we refrained from multiple counting of the same worst invasive species in a country even if the species originated from multiple overseas territories. This was particularly observed for species with little to no data available for calculation. Such worst invasive alien species are likely to be included (counted) in S_{Nat} by Turbelin et al. (2017), though a significantly positive relationship between the data on S_{Nat} and those on S_{Worst} across all the examined countries ($p < 0.01$) was still interesting. In other words, the two datasets are consistent with each other, suggesting that the World's 100 Worst Invasive Alien Species originated from the countries where many invasive alien species in other countries were originally distributed as native species. We, therefore, used the arithmetical mean based on the two datasets to obtain national contribution rates to biodiversity loss by invasive alien species.

The distribution and impact of invasive alien species have been shaped by a long history of natural and anthropogenic activities; however, due to the lack of data, our calculation was limited to two datasets of different years– 2013 and 2016. Nevertheless, the data we employed are likely to represent each country's impact on invasive alien species for more than a few decades.

3. Results and discussion

3.1. Review of relevant publications

Table 1 presents the relevant publications reviewed in this study. Amongst these, the study conducted by Lenzen et al. (2012) suggested that there were differences in the responsibility among countries by quantifying the impacts on a global scale with respect to biodiversity conservation. They associated biodiversity-related products with threatened species listed on the International Union for Conservation of Nature (IUCN) Red List to assess the impact of the supply chains of implicated products. The results showed that production activities of exporting developing countries for consumption of developed countries such as the US, Japan, and the EU were associated with 50–60% of all domestic threats to biodiversity. They concluded that the responsibility for the biodiversity impacts had to be shared between the producers and consumers of the supply chain.

Meanwhile, the work of Moran and Kanemoto (2017) applied the methodology of Lenzen et al. (2012) and added a spatial analysis to map the extent to which countries are impacting biodiversity around the world. Hoang and Kanemoto (2021) showed that the G7 countries, except for Canada, have increased their forest areas while deforesting more than the increase through imports from distant countries including Brazil and Southeast Asian countries.

Similarly, Holland et al. (2019) analyzed the impact of the global electric power sector on biodiversity using Multi-Regional Input Output (MRIO) modeling and the IUCN Red List. Sun et al. (2022) used the Human Development Index (HDI) as a weighing parameter in considering the responsibility-sharing of footprints derived from production and consumption. Their study suggested that the footprints of the Global North shared more responsibility compared through other assessment methods.

Sarkodie (2021) evaluated the difference in Ecological Status and found a high Ecological Deficit (EF > Biocapacity) in the US, China, Japan, India, and Germany, and a superior Ecological reserve (EF < Biocapacity) in Brazil, Canada, Australia, Congo, and Bolivia, and suggested that population density affected the EF.

Although the concept of CBDR was not explicitly brought up or discussed in these publications, they showed and quantitatively assessed the impact on biodiversity at a country level from specific perspectives. In light of such data, it can be argued that quantitatively different targets or differential treatments could be set among countries for the conservation of biodiversity in the CBD context (Ohsawa et al., 2019; Linares, 2022). However, there are still three major challenges in translating these existing studies into practices or contributing to actual policy-making. These challenges are elaborated below.

3.1.1. Coverage of direct drivers of biodiversity loss

Direct drivers of biodiversity loss are not limited to deforestation and species extinction through supply chains. According to the IPBES Global Assessment Report on Biodiversity and Ecosystem Services (IPBES, 2019), direct drivers of change in nature with the largest global impact include, in order of impact, changes in land and sea use, direct exploitation of organisms (including fishing and hunting), climate change, pollution, and invasion of alien species. Yet, none of the publications reviewed (Table 1) had compared the responsibility among countries by considering all these five direct drivers, which made these publications limited evidence as the basis for sharing responsibility for biodiversity conservation. In particular, few studies quantified each country's responsibility for the global impacts of invasive alien species.

3.1.2. Availability of data over a long period

There is an argument in the discussion on CBDR that developed countries' responsibility for the environment should be evaluated, considering the burden that has been brought over a long period of time since the Industrial Revolution. For example, in the discussion of the post-2020 GBF, while many argued that the period of 2011–2020 should be used as the "reference period" for assessing progress, a few parties pointed out that a pre-industrial period should be used (Linares, 2022; SCBD, 2022b). However, in reality, the availability of the methods and data that cover such a long reference period data may differ depending on regions and taxa.

Although it is controversial whether it is better to use the pre-industrial period as a reference, we explored data over a long period of time as much as possible to consider the feasibility of a time-series calculation and examination of the applicability of the CBDR principle. However, our review showed that despite the availability of data from different periods, the existing studies used data from a single year and not in a chronological manner, thus, the contribution over time was not efficiently assessed. Furthermore, unlike carbon dioxide, which remains extremely stable in the atmosphere once emitted, natural capital can regenerate. Therefore, when conducting a long-term assessment, it is desirable to consider not only the impact of anthropogenic activities but also changes over time due to regeneration. This point should be recognized as a major difference with climate change.

3.1.3. Lack of evaluation of positive impacts

The review conducted showed that there were no studies or existing published literatures that evaluated the extent to which countries have made positive contributions in light of their responsibilities. A typical example of a positive contribution is the international (bilateral and multilateral) financial contribution for biodiversity based on Articles 20 and 21 of the CBD. Such contributions are likely to be proportionate to countries' capabilities, though we need to differentiate the two as "already fulfilled responsibilities" vs. "capabilities". The Ecological Reserve can also be regarded as having a positive non-monetary impact on biodiversity conservation.

For evidence-based policymaking, the gaps, or unfulfilled responsibilities, need to be identified by matching negative contributions with positive ones. However, the data on positive contributions are limited except for the ones mentioned above. For example, currently, there are no data regarding countries that serve as sinks for pollutants originating in other countries or countries that reduce these environmental burdens and mitigate their spread to other countries.

3.2. Comprehensive evaluation of individual country's contribution to biodiversity loss

Based on the evidence gap in CBDR discussions in the field of biodiversity identified in the previous chapter, we evaluated the individual country's contribution to the five direct drivers of biodiversity loss presented by the IPBES (IPBES, 2019).

3.2.1. Quantification of the contribution to the five direct drivers

The contribution rate of countries to biodiversity loss based on income categories is shown in Fig. 1. The largest contribution to biodiversity loss came from 33 high-income countries, accounting for 38.9% of the total. Meanwhile, there were 35 middle-income countries and 61 low-income countries that contributed 18.5% and 25.3% of biodiversity loss, respectively. Hence, 43.8% of the global biodiversity loss was attributed to developing countries. In addition, the contribution rate from the footprints that were not allocable to any country accounted for 17.3%. The average contribution rates per country for high-, middle-, and low-income countries were 1.1%, 0.5%, and 0.4% respectively, with a significant difference of about 2.5-fold (Welch's *t*-test, $p < 0.05$) between developed and developing countries. On the other hand, there were no significant differences in the average between any of the pairs of high-, middle- and low-income countries based on Welch's One-Way Analysis of Variance and Games-Howell Post-hoc Multiple Comparison test ($p > 0.05$).

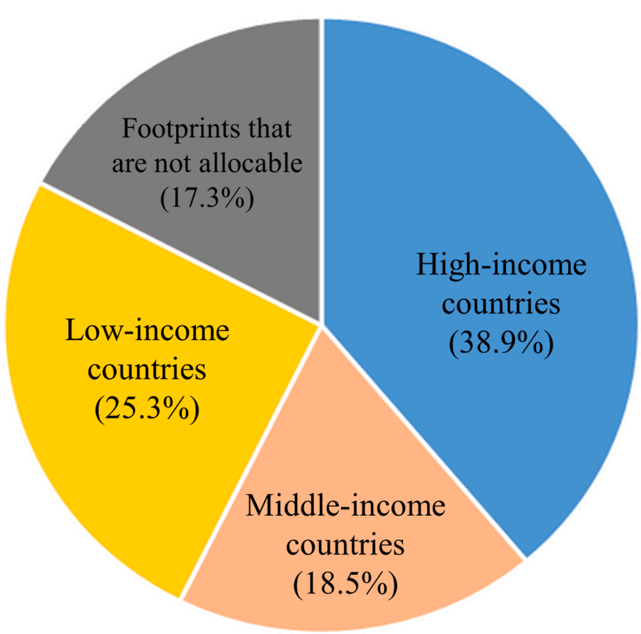

Fig. 1. Percentage contribution of high-, middle-, and low-income countries to five direct drivers of biodiversity loss. The country classification is based on the income classification by the World Bank (2021).

Fig. 2 presents the individual countries' contribution to biodiversity loss based on income categories. Amongst the 129 countries, the countries that made the largest contribution were, in order from the top, Japan, India, China, the US, the UK, Italy, Germany, Spain, France, and the Republic of Korea. Algeria (11th) and Mexico (18th) made the largest contributions in the African and Latin American regions, respectively. The top ten countries accounted for 46% of biodiversity loss, with the top five accounting for 34%. A small number of countries account for a large share while the rest of the share is a mixture of all three income categories – high, middle, and low. This possibly leads to the result that no significant differences were found in the average between any of the pairs of categories.

As suggested by several studies (Lenzen et al., 2012; Hoang and Kanemoto, 2021; Sun et al., 2022), our result also showed that the largest contribution to biodiversity loss came from high-income countries. In particular, the G7 countries, except for Canada, were among the top ten most impacted countries. On the other hand, two of the top ten countries were a middle-income country (China) and a low-income country (India), and the top 13 countries that made up 50% of the contribution included India, China, Algeria, Russia, and Nigeria. These results suggested that while developed countries are relatively responsible, the share of responsibility was not clear enough to be sorted out simply by the dichotomy between developed and developing countries. In other words, while the CBDR principle was worth considering, the simple dichotomy that divides all countries into developed and developing countries based on the principle could lead to an over- or underestimation of the responsibility of some countries.

Moreover, Table 2 shows the top five countries with the largest contribution to each direct driver, indicating notable differences in the composition of major contributors among the drivers. For land-use change and climate change, high- and middle-income countries made the largest contributions, with Japan (4.0%) and the US (3.4%) as the leading contributors, respectively. Meanwhile, for overexploitation, a combination of low-, middle-, and high-income countries occupied the top five ranks, with India as the top contributor (6.2%). For pollution (water) and invasive alien species, low- and middle-income countries accounted for four and three of the top five countries, respectively. Thus, when looking at a specific driver or drivers, the CBDR principle could not necessarily be valid.

3.2.2. Quantification of the contribution to biodiversity conservation

We compared the positive contribution of each country to biodiversity conservation (i.e., financial contribution) against the contribution rate to biodiversity loss. Under the CBD, resource mobilization reports have been submitted and published by the parties, and these reports are the most comprehensive source of data. However, the number of countries that have done so is limited, and various calculation methods are used to report their mobilized resources (SCBD, 2020a). For these reasons, we adopted the data on the bilateral Official Development Assistance (ODA) between 2002 and 2019 from the Organization for Economic Co-operation and Development (OECD) Creditor Reporting System. We used the Rio Marker methodology and counted biodiversity-related flows (i.e. "significant" and "principle" flows). ODA from EU institutions was allocated to EU member countries by multiplying the ratio of individual country's financial contribution to EU's total expenditure (European Commission). In addition, contributions to the Global Environment Facility (GEF), the financial mechanism of the CBD, were used as multilateral financial contributions(SCBD, 1995; SCBD, 1996) . The amount of contribution since 1994 (from GEF-1 through GEF-7) was multiplied by 22.57%, which is the percentage that funding decisions approved for the biodiversity field in the total funding provided (GEF, 2021). Due to data constraints, the financial data of a few countries were limited to their ODA or GEF contributions.

Among the 51 countries which have provided finance through ODA and/or GEF, Germany was the top donor followed by Japan, which had the largest contribution to biodiversity loss (see Supplementary Table 2

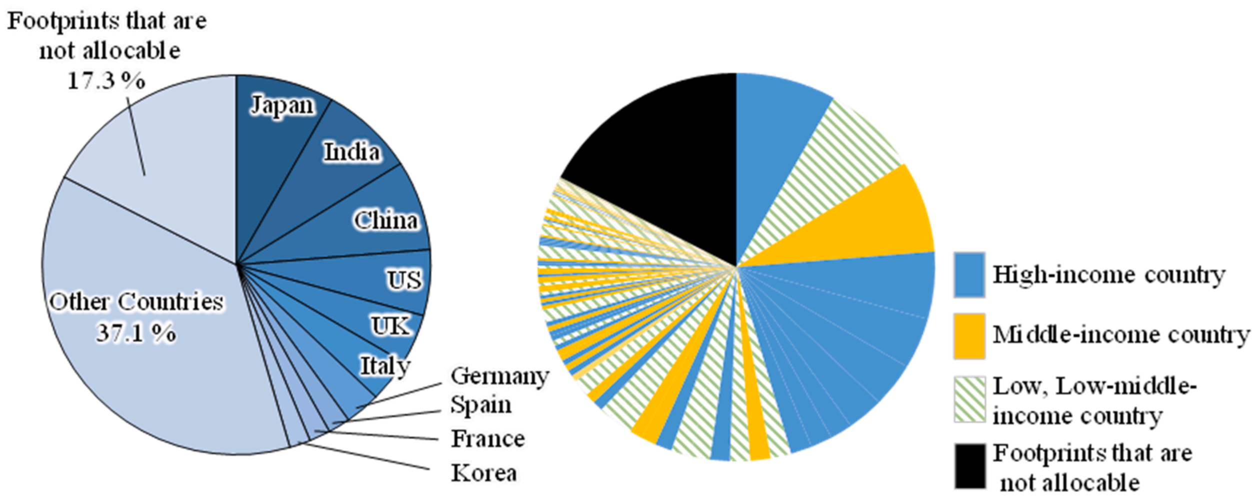

Fig. 2. Individual countries' contribution to the five direct drivers of biodiversity loss (left) and per income category (right).

Table 2
Top five countries that have high contributions to direct drivers of biodiversity loss. The percentages show the contribution rates to global biodiversity loss.

Rank	Land-use change	Over-exploitation	Climate change	Pollution (water)	Invasive alien species	Total
1	Japan (4.0%)	India (6.2%)	US (3.4%)	China (1.3%)	France (0.31%)	Japan (8.2%)
2	China (3.7%)	Japan (3.2%)	China (2.5%)	US (0.73%)	China (0.26%)	India (7.9%)
3	Italy (2.8%)	Ethiopia (1.5%)	Russia (1.0%)	India (0.64%)	US (0.22%)	China (7.7%)
4	UK (2.3%)	Nigeria (1.4%)	Japan (0.74%)	Russia (0.22%)	India (0.22%)	US (5.6%)
5	Germany (2.0%)	UK (1.4%)	Germany (0.62%)	Brazil (0.11%)	Mexico (0.21%)	UK (4.3%)

in Supporting Information). India and China, which ranked second and third in terms of negative contribution, respectively, were ranked 19th and 18th out of 40 GEF donor countries. It should be noted that bilateral ODA data from these two countries were not available, and they ranked 2nd and 1st, respectively, in terms of GEF contribution when high-income countries were excluded.

Fig. 3 shows the relationship between the country's contribution rate to biodiversity loss and financial contribution to biodiversity conservation efforts. The linear regression line implies the average results for 25 countries where both ODA and GEF data were available. Among the top ten countries with large negative contributions, Japan, Germany, the US, and France have provided higher positive contributions compared with the linear regression line for contribution rate to biodiversity loss and financial contributions, while the UK, Italy, Spain, and Korea have provided lower contributions. The low R-squared indicates that each country's negative impact on biodiversity and its financial contribution are not necessarily proportionate, while, in general, countries with large impacts on biodiversity tended to have high positive contributions to conservation through funding. It implies that there is room for certain countries to improve their budget allocation processes based on their negative impacts on biodiversity.

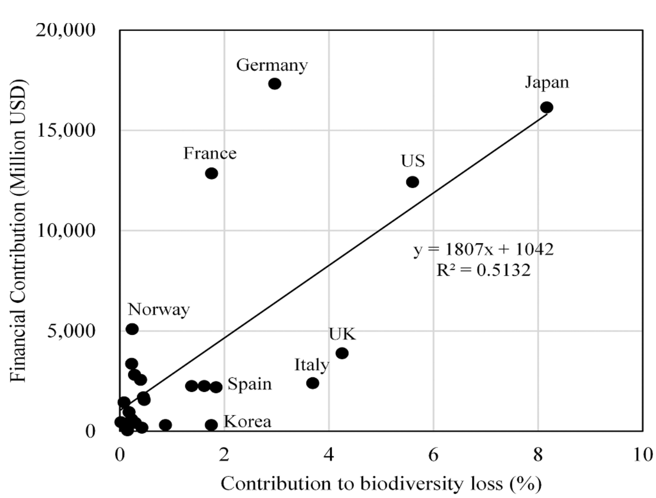

Fig. 3. Relationship between the country's contribution rate to biodiversity loss and financial contribution to biodiversity conservation efforts. The financial contribution includes cumulative bilateral ODA (2002~19, unit: million USD) and cumulative contribution to the Global Environment Facility (1991~2022), as of 8 Apr 2022. Among the 51 countries, only 25 countries where both ODA and GEF data are available are shown here.

3.2.3. *How to utilize the quantified data in actual policy-making*

The CBDR principle has been discussed with a strong emphasis on the responsibilities of developed countries due to their past contributions to biodiversity loss as well as their capabilities. In developed countries, many citizens may have supported their ODA, including measures against environmental issues, since they are simply cognizant of the importance of global cooperation to address global issues (e.g., Cabinet Office of Japanese Government, 2022). To our knowledge, such funding by developed countries has not been calculated based on the contribution rate to biodiversity loss, such as EF. Rather, national capabilities, such as Gross National Income (GNI), have been considered as a kind of criteria to determine each country's financial contribution to global conservation (e.g., SCBD; Luck et al., 2009; United Nations, 2022). Thus, in the future, evidence of environmental responsibilities, such as the one presented in this study, can be used as a scientific basis for financial contributions. For example, if globally required biodiversity finance is given, the budgetary share of each country can be calculated by multiplying its contribution rate to biodiversity loss. These data can serve as basis to justify or encourage such provisions for countries in their contribution to international biodiversity funding with increased precision. Moreover, driver-based data on each country's responsibility for biodiversity loss may allow them to understand which driver(s) should be prioritized to address.

Although we used the five direct drivers of biodiversity loss presented by the IPBES, approximately 17% of the total contribution rate was not allocable to any countries due to data constraints. Drivers such as human disturbance, recreational activities, and tourism were not assigned to any of the countries. Furthermore, both consumer (importer) and producer (exporter) countries gain benefits from any production industries, yet the EF is mainly attributed to consumer countries of each product. The producer countries, which produce goods to meet the demands of consumer countries, are not included. We argue that the responsibility for the environmental impact due to trade should be fairly attributed to both consumer (often developed countries) and producer countries (developing countries). Thus, responsibility should also be shared among related countries in a fair way balancing "common" and "differentiated" in light of environmental responsibility. Thus, "differentiated but shared responsibilities (DBSR)" will be challenging yet relevant for future assessments and policy-making (Fig. 4).

Given the complexity of biodiversity and various drivers of its loss and degradation, we suggest that the responsibility of individual countries be assessed in a comprehensive way as in this paper. Since Figs. 1 and 2 suggest that the responsibilities are not one-sided between developed and developing countries, "differentiation" of responsibility needs to be done more carefully, scientifically, and quantitatively.

Besides, among the 129 targeted countries, in comparison to 1992, when the CBD was adopted, there were 11 countries that moved from a low- or middle-income group to a high-income group in the World Bank group classification (from 22 to 33 countries), from which the total contribution to biodiversity loss was 4.4%. These countries included, among others, some European countries (Greece, Portugal, Poland, etc.), Chile, and Korea. Similarly, there were 24 countries with 13.4% of contributions moved from a low-income group to a middle-income group (e.g. China, Guatemala, Peru, Russia, Turkey). If national capabilities are also considered together with environmental responsibilities, as embedded in the concept of CBDR-RC, the contribution of these income-increasing countries must be assessed in a timely manner. In reality, however, the list of developed countries in the decision adopted by the conference of the parties to the CBD at its first meeting (SCBD, 1995) was revised only once more than 15 years ago, adding only three countries (from 22 to 25) as developed countries (SCBD, 2006). Therefore, CBDR-RC is not being implemented with sufficient evidence in actual policies. In summary, the respective capabilities have not been considered in a timely manner in policy-making. Hence, DBSR and "updated capabilities" (DBSR-UC) are relevant to allocating financial burdens among countries for biodiversity conservation.

3.2.4. *Research limitations and future works*

There are five limitations that can be considered for future studies (Details given in Supporting Information). First, data are still lacking for certain countries depending on periods and direct drivers, which may lead to underestimating the countries' contribution to biodiversity loss. Having said this, it will not be realistic to precisely evaluate contributions to biodiversity loss with a reference level to pre-industrial times, which certain Parties raised during the CBD negotiations (SCBD, 2022a). This will be left for the policy-makers to address or come up with a more realistic timeframe. Second, while positive contribution to biodiversity was measured using international financial contribution, it could be complemented by other indicators such as non-monetary efforts to conserve biodiversity or domestic resources if common measurement methods are to be developed in the future. Third, responsibility could be shared between producer and consumer countries in a more complex manner under the framework of DBSR. The demands from the consumer side and supply from the producer side are closely interlinked. Fourth, any synergistic or trade-off effects were not considered amongst drivers, though, for example, it is expected that invasions of non-native species will expand to the temperate and subarctic regions in the future as climate change progresses. Hence, future studies need to determine how the share of responsibility could be allocated equitably considering such interlinkages among drivers. Fifth, when considering CBDR-RC for

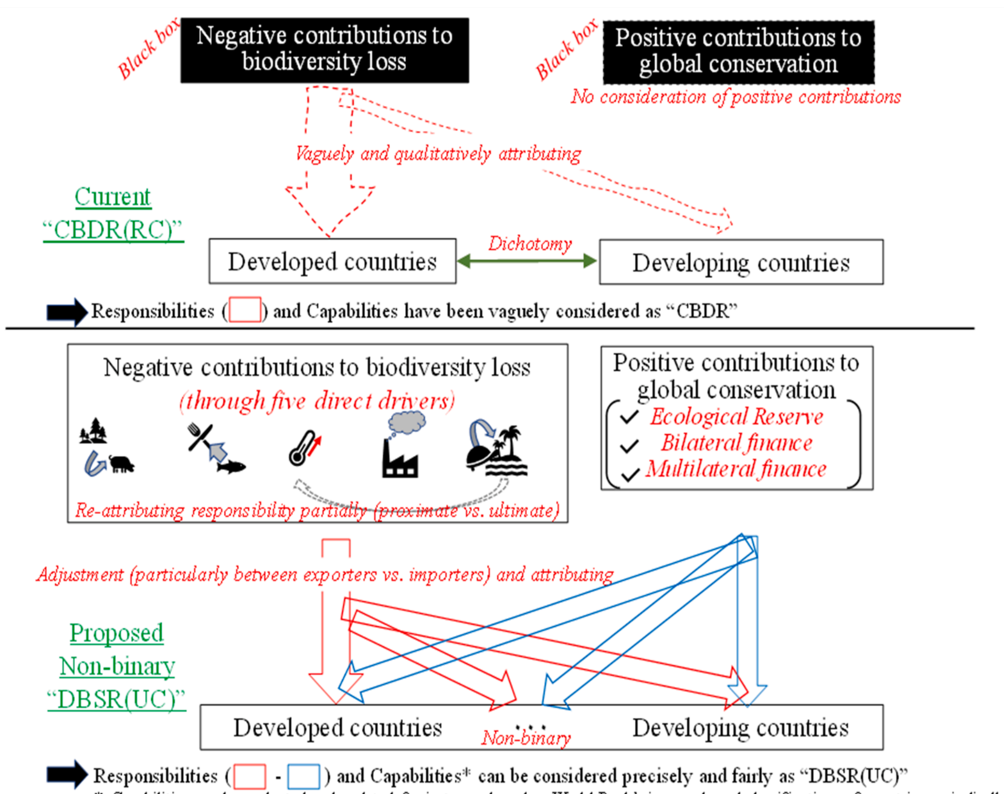

Fig. 4. Current concept of "Common But Differentiated Responsibilities (and Respective Capabilities)" (CBDR-RC) and proposed concept of non-binary "Differentiated But Shared Responsibilities (and Updated Capabilities)" (DBSR-UC).

allocating burdens among countries for global biodiversity conservation, we need to decompose this concept into CBDR and RC. In other words, we need a mechanism to consider both responsibility (biodiversity loss caused by the individual country) and capability (including financial situation) for the burden calculation.

4. Conclusion

We evaluated the applicability of the "Common But Differentiated Responsibilities" principle to the biodiversity processes, including the GBF as post-2020 target. The results indicated that the contribution rate to biodiversity loss by high-income countries was the largest at 38.9%, indicating that the responsibility of developed countries was relatively large. Alternatively, certain middle-income and low-income countries also contributed significantly, and the contribution of developing countries as a whole was 43.8%. Thus, simply dividing all countries into developed and developing countries based on this principle would be inappropriate while CBDR is a principle worth considering as starting point. Consequently, the propose non-binary DBSR will be potentially more suitable concept for future policy-making, highlighting the need for all countries to act to halt biodiversity loss. Simultaneously, respective capabilities should be considered together with the environmental responsibilities as key components of DBSR-UC. The capabilities need to be evaluated and updated, for instance, based on the World Bank's income-based classifications of countries periodically.

From the results, the countries with large contributions to biodiversity loss have already supported by large positive contributions to biodiversity (through financial contributions). However, in the future, all countries need to further fulfill their responsibilities for biodiversity loss including strengthening their efforts to reduce footprint and financial contributions based on the evidence.

Methodologically, our literature review indicated that there were no studies that covered and quantified all five direct drivers of biodiversity loss. Thus, we calculated the contribution rate to biodiversity loss of each country based on the percentage of the impact of each driver presented in the IPBES Global Assessment Report (IPBES, 2019) and various footprints based on the available data. We evaluated the limitations and their implications for future works. Particularly relevant for methodologies, synergistic or trade-off effects were not considered amongst drivers. These remain as future challenges besides other limitations such as availability of data, variety in positive contribution, relationships of producers and consumers, or political feasibility of the CBDR-RC.

CRediT authorship contribution statement

Hiroaki Tomoi: Conceptualization, Methodology, Investigation, Formal analysis, Visualization, Writing – original draft. **Takafumi Ohsawa:** Conceptualization, Methodology, Investigation, Formal analysis, Visualization, Writing – original draft. **Jay Mar D. Quevedo:** Methodology, Validation, Visualization, Writing – review & editing. **Ryo Kohsaka:** Conceptualization, Writing – review & editing, Project administration, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolind.2022.109628.

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