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Adapting double-entry bookkeeping to renewable natural capital: An application to corporate net biodiversity impact accounting and disclosure

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ABSTRACT

Both internal and external stakeholders of organisations are increasingly aware of the importance of natural capital in creating sustainable value. Corporate reporting on natural capital has been growing considerably over the past couple of decades, particularly for issues such as climate change, water and waste. Yet, quantified data disclosed is currently essentially limited to annual flows, such as resource use or emissions, failing to account for net impact on natural capital. This paper proposes new conventions to double-entry bookkeeping to facilitate net biodiversity impact accounting and disclosure. Case study applications involve assessing the net ecosystem impacts of both the Nimes-Manduel-Redessan train station and Cossure offset projects, in the South of France, to record the periodic and accumulated changes in ecosystem extent and condition, without compromising the incommensurability of biodiversity components. Assuming the two projects belong to the same business, the scaling up of project-level data and their aggregation at the company level are demonstrated through the development of Statements of Biodiversity Performance and Position.

1. Introduction

1.1. Business impacts and dependencies on renewable natural capital

Natural capital refers to the stocks of renewable and non-renewable natural resources (e.g., plants, animals, air, water, soils, minerals) and the associated flows of ecosystem services which benefit people and companies (Natural Capital Protocol, 2016). Biodiversity is an integral part of natural capital and interaction between its components ensure the quality, quantity and reliability of various ecosystem services. For business specifically, natural capital can be perceived as a set of resources and benefit streams to reach organisational outcomes, such as critical production factors (e.g., raw materials, energy, genetic materials) and natural risk mitigation services (e.g., flood regulation and crop disease regulation services) provided by well-functioning ecosystems (Houdet et al., 2012). At the same time, natural capital stocks and their capacity to supply ecosystem services can be impacted by business in two main ways (TEEB, 2012):

- Dependencies: Through their use or extraction for production processes (e.g., water abstraction for mining, fishing or wood harvesting);
- Impacts: Through the changes caused by business activities when impacting ecosystems (e.g., land use change, invasive species introductions, waste generation, water and air emissions).

Depending on the context, changes in the availability, reliability or quality of renewable natural capital, including biodiversity, may generate different types of risks for business (e.g., changes in resource availability, degradation of ecological infrastructure, water quality and aquifer recharge). This, in turn, may lead to changes in capital and operational expenditures (e.g., additional supply/procurement costs, new technological requirements) or fluctuations in sales (e.g., product boycotts) (Houdet et al., 2012). Indeed, changes to natural capital are at the core of numerous internal and external stakeholder relationships, at various steps in the value chain, with important and increasing effects on corporate image and the social licence to operate.

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1.2. Why net changes in renewable natural capital matter to business

Sustainably managing and conserving renewable natural capital[1] involve complementary factors, including their ability to sustain (renew) themselves (e.g., sufficient space and time to do so) and the implementation of cost-effective management systems (TEEB, 2012). To support this, reliable and regular assessments of changes in stocks and flows (e.g., amounts of extracted resources), in both space and time, as well as in terms of integrity, are required. In other words, to understand whether a business sustainably manages a specific renewable natural capital stock, it needs to go beyond monitoring natural capital flows and be able to understand the status (amount, condition, location) of the stock it interacts with and track the changes in stocks due to its activities and, potentially, those of other economic agents that may also rely on these stocks.

In doing so, the company would be expected to be in a position to understand the level/extent of its impacts and dependencies and whether management activities are effective in sustainably managing or conserving renewal natural capital (Houdet et al., 2010, 2014. This is the type of information that both internal and external stakeholders require in order to make informed decisions (e.g., resource management and investment choices, share purchase/sale, social licence to operate).

1.3. Existing corporate approaches neither account for nor disclose net impacts on renewable natural capital

Various frameworks and standards[2] have been developed and implemented over the past 15 years to improve extra-financial accountability for the benefit of both internal and external business stakeholders. For companies, this involves participating in a mix of public and private sustainability reporting practices, private reporting often aiming at providing supplementary information on selected issues (especially climate change and governance issues) to institutional investors. In the end, companies are using four main, often complementary ways to report on natural capital impacts and dependencies to date (Houdet et al., 2010, 2014):

- Narratives about the company's management approach are used to explain how reporting organisations deal with a specific natural capital issue;
- Financial information may be disclosed to explain the financial implications or consequences of a specific event (e.g., mine closure liability, oil spill fines);
- Quantitative non-monetary information is disclosed to express how the reporting organisation uses and/or impacts natural capital;
- Information on externalities, in monetary units, disclosed by a very limited number of companies to date (e.g., de Adelhart Toorop et al., 2016; BSO/Origin – Huizing & Dekker, 1992; Novo Nordisk – Danish Environmental Protection Agency 2014; Kering 2014), is used to present the uncompensated economic impacts on society generated by the reporting organisation (e.g., economic costs of air emissions).

While quantitative non-monetary information is the only approach which may disclose net natural capital impact in bio-physical terms, it is currently limited to key performance indicators (KPI) that cover inputs and outputs (flows) of the reporting organization:

- Non-product outputs or emissions such as greenhouse gas (e.g., GHG Protocol scopes 1, 2 and 3 – World Resources Institute, World Business Council for Sustainable Development, 2004; GRI 305 indicators – GRI 2016), hazardous waste and spills (e.g., GRI 306 indicators – GRI 2016).
- Amounts of material inputs such as material used (weight or volume) (e.g., GRI G4 – EN1 indicator) and water withdrawal by source (e.g., GRI G4 – EN8 indicator).

In other words, the underlying changes in natural capital stocks (e.g., stocks of renewable resources, air or water quality) are not disclosed to stakeholders. Such disclosures do not explicitly refer to a baseline year but are valid only for the reporting period, typically for a timeframe of a year preceding the disclosure (e.g., amount of materials used over the financial reporting period). This leads to a series of annual disclosures with no information on net impacts or changes since a relevant baseline year (e.g., starting date of resource exploitation or emission generated).

Moreover, several Environmental Management Accounting (EMA) methods, systems, tools and/or standards have been developed for business over the years (e.g., Burritt et al., 2002; Burritt et al., 2011; Richard 2009; Schaltegger and Burritt, 2017). EMA methods may make use of biophysical and/or monetary information, have a short- or long-term focus, have different timeframes (past, present and/or future) and may be *ad hoc* or based on the routine gathering of information. Yet, none of these approaches provide a framework to account for net impact on natural capital: i.e. accounting for both changes in stocks and flows in bio-physical terms. While monetary EMA approaches fail to provide quantified net natural capital impact information[3] (e.g., these focus on the monetary impacts of environmental issues on business, such as accounting for the cost of non-product outputs), physical EMA approaches currently do not show net changes or impacts beyond a single reporting period (e.g., only periodic impact drivers and impacts are assessed through the use of the GHG Protocol and Water Footprint Standard).

In other words, existing accounting and disclosure models do not address the main issue facing reporting organisations about natural capital accountability. They do not offer reporting organizations ways to disclose information about net natural capital impacts and thus prevent stakeholders from understanding whether management activities are effective in sustainably managing or conserving renewable natural capital.

2. Proposed approach and case studies

Biodiversity – the variability of life on earth from genes, species to ecosystems – is a critical component of natural capital. Yet, it is often totally undisclosed or only partially represented as a stock of natural capital in business-focussed natural capital assessments (Cambridge Conservation Initiative 2016). As shown by Addison et al. (2018), in their assessment of the top 100 of the 2016 Fortune 500 Global companies' sustainability reports, 49 of the Fortune 100 mentioned biodiversity in their reports, and 31 made clear biodiversity commitments, of which only 5 were specific, measurable and time bound. A variety of biodiversity-related activities were mentioned (e.g., managing impacts, restoring biodiversity, investing in biodiversity), but only 9 companies provided quantitative indicators to disclose the magnitude of their activities (e.g., area of habitat restored). Besides, these quantitative estimates of beneficial activities for biodiversity are never compared to the quantified magnitude of negative impacts on biodiversity that these companies generate. As expressed by several key stakeholders (e.g., Convention on Biological Diversity's business engagement on

[1] Non-renewable or exhaustible natural capital stocks cannot be sustainably managed in themselves: the only option is to manage the rate of exploitation or use.

[2] E.g., Climate Disclosure Standards Board (CDSB) framework for reporting environmental information and natural capital, Global Reporting Initiative - GRI G4 guidelines, CDP disclosure programs – e.g., on climate change and water, Sustainability Accounting Standards Board (SASB) sectoral standards.

[3] Monetary valuation does not support the incommensurability of renewable natural capital, especially biodiversity components (e.g., Farrell, 2007).

reporting[4] and the *Aligning biodiversity measures project* led by UNEP-WCMC (2016)[5]), there is a need for biodiversity impacts to be accounted for and disclosed at the group level.

This paper adapts double-entry bookkeeping (DEBK), which originated in financial accounting, to account for and report on net biodiversity impacts. Biodiversity impacts are defined as the negative or positive effects of business activity on biodiversity, which may be generated by either or both natural capital dependencies and impacts. In biodiversity accounting, positive impacts are gains while negative impacts are losses. Biodiversity impacts typically refer to changes in:

- The population size and viability of species;
- The extent and condition of ecosystems.

Two case studies are used to test whether DEBK can be used for corporate biodiversity accounting and disclosure, with a focus on changes in ecosystem extent and condition, a key component of biodiversity impacts. This section is broken down into three sub-sections, namely:

- An explanation of how the mitigation hierarchy underpins the development of a net impact accounting model,
- An introduction of DEBK and its adaptation to corporate accounting for the impacts on ecosystem extent and condition, and
- A brief presentation of the selected case studies.

2.1. Accounting for net impact through the mitigation hierarchy

The mitigation hierarchy refers to the sequence of actions taken to anticipate and avoid impacts on biodiversity and ecosystem services; and where avoidance is not possible or sufficient, minimize or reduce impacts; and, when impacts have nevertheless occurred, rehabilitate or restore the affected biodiversity components. This concept is widely used throughout the world and is often embedded into national legislation as regards to environmental impact assessments (BBOP, 2012; Bull et al., 2013; Maron et al., 2018).

The use of the mitigation hierarchy is often linked to an overarching goal/objective of no-net-loss (NNL) or a net positive impact (NPI) for biodiversity for a whole project, which requires an assessment of the baseline or existing conditions at a particular time to provide a starting point (e.g., pre-project condition of biodiversity) against which comparisons can be made (e.g., post-impact condition of biodiversity), allowing changes in biodiversity to be measured throughout the project life-cycle. No net biodiversity impact thus refers to the point where biodiversity gains from targeted activities (e.g., impact mitigation, restoration/rehabilitation and offset measures) match the biodiversity losses generated by the company's impacts on the targeted biodiversity stocks, relative to an explicit reference. Net positive biodiversity impact refers to the point where biodiversity gains from targeted activities exceed biodiversity losses generated by the company's dependencies or impacts on biodiversity, also relative to an explicit reference. This is exactly what is currently missing from corporate natural capital reporting and disclosure: The ability to assess what is the net impact.

The mitigation hierarchy has been applied to both natural capital flows (e.g., a business non-product output such as greenhouse gas emissions or wetland hydrological functions that regulate up- and down-stream water flows) and various stocks of biodiversity (various habitat types and species, including commercial fish or timber stocks) (Houdet et al. 2014). It has been used for a growing number of projects worldwide (e.g., property development, linear infrastructures, mines; ten Kate et al., 2014; Gamarra & Toombs, 2017; Wende et al., 2018), typically in the context of project permitting processes (Bull & Strange 2018). In 2016, there were 18 companies with active corporate NNL/NPI biodiversity commitments (de Silva et al., 2019). The challenge is to develop an accounting framework that enables organisations to scale up net impact data of any business activity to aggregated company-level impacts.

2.2. Adapting conventional DEBK to account for net biodiversity impacts

Financial accounting is the process of recording, summarizing and reporting the myriad of transactions resulting from business operations over a period of time and across different geographies where the business is operated. Financial accounting is based on DEBK, whereby every financial transaction entered into an account has an equal and opposite effect in at least one other account (e.g., Trotman & Gibbins, 2003). These transactions are summarized in the preparation of financial statements, including the Statement of Financial Position (or Balance Sheet) and Statement of Financial Performance (or Profit & Loss Statement). DEBK thus enables businesses to record both periodic and accumulated changes in transactions of a financial nature and to aggregate individual financial events at the company level.

More specifically, the Statement of Financial Position is built upon a single equation whereby the assets of the company are either financed through debt/liability or owner's equity. This equation provides a condensed summary of the results all the transactions the company has entered into up to the end of the financial year. It covers the transactions of the past financial year and those of prior years as all balance sheet accounts are carried over from a financial year to the next.

(a) Equation of the Statement of Financial Position (Balance Sheet):
Assets = Liabilities + Owner's Equity.

The Statement of Financial Performance is simpler: Periodic profit or loss is calculated by subtracting expenses from revenues over a period, typically a financial year. This periodic result is integrated into the balance sheet at year end in the owner's equity part of its equation (e.g., profits retained by the company).

(b) Equation of the Statement of Financial Performance (Profit & Loss Statement):
Profit/Loss = Revenues – Expenses.

In short, DEBK allows companies to account and disclose both periodic performance, through the Statement of Financial Performance, and the net (or accumulated) result of past periodic performances via the Statement of Financial Position. To test whether DEBK can enable organisations to account for and disclose their net biodiversity impacts over time, both on an periodic basis and from a historical perspective (i.e. accumulation of impacts to date from the inception of the company or a chosen baseline year to date), we propose two equations to establish the Statement of Biodiversity Position and the Statement of Biodiversity Performance. To do so, we focus our analysis to changes in ecosystem extent and condition as a key component of biodiversity impacts.

In reference to the Statement of Financial Position (Balance Sheet), the Statement of Biodiversity Position (or Biodiversity Balance Sheet) represents the ecosystem assets of the reporting organisation at a specific time (e.g., from the time of the first ecosystem impact assessment, based on a chosen baseline or the start of the business activity up to the present time) and the associated accumulated positive and negative impacts.

[4] URL: https://www.cbd.int/business/projects/reporting.shtml, accessed on October 16, 2019.

[5] E.g., Aligning biodiversity measures project. URL: https://www.unep-wcmc.org/system/comfy/cms/files/files/000/001/556/original/20190614_AligningMeasuresFlyer_Communications_FINAL_210619.pdf, accessed on October 16, 2019.

(c) Statement of Biodiversity Position[6] (or Biodiversity Balance Sheet)
Biodiversity assets (ecosystem extent accounts in hectares) (A) = accumulated positive impacts (condition-adjusted ecosystem extent accounts in hectares equivalent[7]) (B) + accumulated negative impacts (condition-adjusted ecosystem extent accounts in hectares equivalent) (C) or
A= B+ C;

In reference to the Statement of Financial Performance (Profit & Loss Account), the Statement of Biodiversity Performance (or Biodiversity Gain & Loss Statement) represents the net changes, gains minus losses, in ecosystem stocks over one year (i.e. periodic changes).

(d) Statement of biodiversity performance:
Net biodiversity impacts (hectares equivalent) (X) = periodic Positive Impacts/Gains (condition-adjusted ecosystem extent accounts in hectares equivalent) (Y) – periodic Negative Impacts/Losses (condition-adjusted ecosystem extent accounts in hectares equivalent) (Z) or
$X = Y - Z$.

However, in order to apply DEBK to corporate impacts on ecosystem extent and condition certain underlying concepts, methods and conventions need to be amended. To ensure the aforementioned DEBK equations hold, the following new biodiversity-specific accounting conventions are proposed:

- First, recognising there is a key difference with financial accounting, where all transactions are expressed in financial values: Biodiversity components are incommensurable so that biodiversity accounting requires the satisfaction of the equivalency principle between biodiversity gains and losses. A company may not use the same metric to account for losses or gains of different components of biodiversity (Quétier & Lavorel 2011; Meinard et al., 2019). In other words, to assess the net impact of a business on biodiversity, it is important to ensure that losses and gains are matched or equivalent for each ecosystem type, extent and condition. For instance, wetland gains through restoration or offset measures cannot offset forest losses. This means that segregated accounts of each type of ecosystem need to be created and monitored.
- Second, recognising that ecosystem categories, irrespective of their condition, constitute biodiversity assets recorded in a surface area metric (e.g., hectare);
- Third, assessing the condition of ecosystem assets is necessary in order to understand changes in biodiversity (i.e. impacts) (see Table 1), with:
- Positive impacts (gains) calculated as the actual condition score, in surface area equivalents (e.g., Ha eq.), of ecosystem assets:
  - Positive impact (condition-adjusted surface area) (P) = nominal surface area (G) multiplied by current condition score (I), divided by the maximum condition score (J), or P = G × (I/J);
  - Negative impacts (losses) calculated as the residual of the nominal surface area (G) minus the actual condition score of ecosystem assets (or positive impact, P), in surface area equivalents (e.g., Ha eq.):
  - Negative impact (condition-adjusted surface area) (N) = nominal surface area (G) minus the actual condition score (or positive impact) of ecosystem assets (P), or N = G – P;
- Fourth, accounting for the reference state of ecosystem assets (A accounts) controlled by the company as theoretical, maximum potential biodiversity gains (Y accounts) is essential to generate a Statement of Biodiversity Position equation. This is because the sum of accounts B + C of the Statement of Biodiversity Position equation (A = B + C) constitutes a continuum of values based on corresponding ecosystem condition scores (hence in Ha eq.) rather than completely separate accounts as in financial accounting (i.e. various debt accounts vs. various owner's equity accounts such as paid-in capital and retained earnings). This critical step underpins the accounting of all future changes in ecosystem extent and condition, at any point in time, and must be undertaken every time new land assets are controlled by the company. This also means that the value of ecosystem assets (in hectares) will always equal the maximum positive biodiversity impact possible (in hectares equivalents) in relation to the selected physical ecosystem boundary.

Furthermore, the following basic steps should be followed to develop ecosystem impact accounts and the associated Statements of Biodiversity Position and Performance across space and time:

- Ecosystem impact inventory development:
  - Definition of relevant scale for adding up units (e.g., hectares, km^2) as appropriate for the business and biodiversity context;
  - Identification and definition of ecosystem stock categories (i.e. list of ecosystem types);
  - Definition of relevant methodology and scale for assessing condition/quality as appropriate for the business and biodiversity context (see Table 1);
  - Collection of data on extent and condition for each impacted ecosystem category (see Table 2);
- Adapting DEBK to record accounting journal entries for ecosystem impacts (see Table 3 for a list of possible journal entries):
  - Accounting for the reference state of ecosystem assets controlled by the company as theoretical, maximum potential gains;
  - Recording ecosystem extent accounts according to their condition scores (i.e. separate ecosystem extent accounts are required for different condition scores) as well as the associated condition-adjusted losses and gains;
  - Accounting for the changes in the condition scoring of ecosystem accounts, which means recording the associated changes in ecosystem extent accounts and the condition-adjusted losses and gains;
  - Compiling the Statement of Biodiversity Performance for the reporting period: This involves recording all changes to ecosystem accounts, with periodic condition-adjusted gains (Y) recorded as credit and periodic condition-adjusted losses (Z) recorded as debits, and eventually calculating the net impacts on ecosystems (X) in hectares equivalents.
  - Compiling the Statement of Biodiversity Position at end of period: This involves recording the residual ecosystem extent accounts (in hectares) as assets (A) and closing the Statement of Biodiversity Performance.

The three key differences with conventional DEBK can be highlighted as follows:

- There are two units in our proposed biodiversity specific DEBK, surface area (e.g., Ha) (A accounts) and surface area equivalent (e.g., Ha eq.) (all other accounts). A accounts can be qualified as measurements (i.e. extent of/amounts of ecosystem assets) while the other accounts constitute mixed quantitative – qualitative values: They express the nature or importance of biodiversity impacts as condition-adjusted surface areas (i.e. positive versus negative impacts expressed in Ha eq.). In conventional DEBK, financial

[6] A (or ecosystem asset) accounts would correspond to assets accounts in conventional DEBK. B (or accumulated positive impact) accounts could be equated to a form of equity accounts in conventional DEBK and, finally, C (or accumulated negative impact) accounts would correspond to liability accounts in conventional DEBK.

[7] Hectare equivalent approaches also factor in the condition or quality of habitats. Different condition rating methods exist.

Table 1
Proposed condition rating system to assess habitat condition for biodiversity account development.[8]

Rating		Description
0	Transformed	Complete losses of natural habitat, biota and basic ecosystem functions.
1	Seriously Modified	The losses of natural habitat, biota and basic ecosystem functions are extensive.
2	Largely Modified	Large losses of natural habitat, biota and basic ecosystem functions have occurred.
3	Moderately Modified	Losses and changes of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.
4	Largely Natural	Small changes in natural habitat and biota may have taken place, but the ecosystem function is essentially unchanged.
5	Natural	No change in natural habitat and biota has occurred.

[8] There are alternative ways of accounting for condition, quality and/or importance. An example is the Biodiversity Metric proposed by Natural England in July 2019, which is available online at URL: http://publications.naturalengland.org.uk/publication/5850908674228224.

Table 2
Assessing the positive and negative ecosystem impacts of a company – total ecosystem impacts (nominal surface area in hectares) equal the sum of positive and negative ecosystem impacts in hectares equivalent.[9]

Ecosystem account category	Nominal surface area (Ha; G)	Condition rating (maximum of 5; see Table 1)	Surface area of positive impacts (Ha eq.; P = G × (I/J))	Surface area of negative impact (Ha eq.; N = G – P)
Grassland (type 1)	100	3	60	40
Grassland (type 2)	50	4	40	10
Forest	500	5	500	0
Wetland	250	1	50	200
Total/Statement of Biodiversity (ecosystem) Position	**900**		**650**	**250**

[9] All examples are fictitious, used for illustrative purposes exclusively.

accounting uses only financial values (single currency).
- There is no immaterial asset in biodiversity impact accounting: Accumulated positive ecosystem impacts (B accounts in Ha eq.) can never be more than the nominal ecosystem extent (A accounts in Ha). This reflects the finite extent of ecosystem assets.
- Finally, the associated values of ecosystem assets (i.e. positive and negative impacts) cannot change according to stakeholders' perceptions of their worth or usefulness (i.e. condition-scoring methodologies assess the quality or integrity of ecosystems). On the other hand, in conventional DEBK, financial values are often used to express the changing worth of the business. For instance, goodwill is recorded in a situation in which the purchase price of a company is higher than the sum of the fair value of all assets less the liabilities.

2.3. Presentation of the case studies

Data availability is often problematic when attempting to assess company impacts on biodiversity. This paper uses exclusively publicly available information from two case studies in France, one linked to an environmental impact assessment process and the other from a biodiversity offset banking project. All the information can be accessed by downloading the two references (Biotope 2017; Dutoit et al., 2015).

The first case study is a project for a new train station (Nimes-Manduel-Redessan or "NMR train station") in the South of France, which is part of a bigger rail network project. The land footprint of the train station and associated developments is 26.11 Ha, including 8.05 ha of urbanised areas. The biodiversity impact assessment process (Biotope 2017) identified four types of land uses/habitats prior to development:

- Fallow land: 4.04 Ha;
- *Brachypodium phoenicoides* grasslands: 2.15 Ha;
- Agricultural lands: 4.76 Ha;
- Diverse land uses with no or very low ecological value (e.g., built areas): 7.11 Ha.

These properties form part of a transformed landscape identified as "plain of Manduel and Meynes", composed mainly of vineyards, orchards and fallow lands. The original ecosystem is identified as "Côteaux de Jonquières Saint-Vincent", a garrigue-type plant community composed of low, soft-leaved scrubs typical of the Mediterranean ecoregion (i.e. 18.06 ha of "natural" or reference state ecosystem with a condition rating of 5 out of 5 – see Table 1).

The second case study is a 'habitat banking' project in the Cossure plain of southern France (the "Cossure offset project") where 12.5 M€ were invested to restore and manage previously-farmed land for a period of at least 30 years so as to sell biodiversity offset credits to project developers who are required to offset their impacts as a condition of their environmental permit (Dutoit et al., 2015). In 2008, 357.00 ha of irrigated orchards were purchased (condition score of 0 for the whole surface area since it was intensively cultivated), located on properties mostly adjacent to an existing nature reserve holding the original ecosystem identified as the Coussoul steppe (i.e. 357.00 ha of "natural" or reference state ecosystem with a rating of 5 out of 5 – see Table 1). While basic restoration activities (e.g., exotic tree species and infrastructure removal) were undertaken over the whole 357.00 ha to generate a grassland fallow favourable to targeted bird species, three additional measures were tested to further accelerate the return of the Coussoul steppe on a portion of the site (Rouvière and Thiévent, 2016):

- The seeding of various species (60.00 Ha);
- The spreading of hay obtained from other Coussoul properties (24.00 Ha);
- The addition of mycorrhizae and vegetative parts to seed mixes (3.00 Ha).

3. Results and discussions

Using the baseline biodiversity data from Section 2.3 and the principles of DEBK with certain modified conventions, the net ecosystem impacts for each case study were calculated and accounted for at all key phases of project development:

- NMR train station: (a) Prior to development, (b) after construction and (c) after offset measures.
- Cossure offset project: (a) on purchase and (b) after completion of restoration measures.

Table 3
The main types of journal entries when adapting DEBK to corporate ecosystem impacts.

Accounting events	Account	Condition score	Debit/credit	Unit	Account category	Comment
Accounting for the reference state of ecosystem assets	Ecosystem asset	5	Debit	Hectare	A (Statement of Biodiversity Position)	Mandatory for recording new ecosystem assets
	Periodic gains	5	Credit	Hectare equivalent	Y (Statement of Biodiversity Performance)	
Recording initial/baseline ecosystem assets according to their condition score	Ecosystem asset	Any, except 5	Debit	Hectare	A (Statement of Biodiversity Position)	Mandatory re-adjustment for all new ecosystem assets, reflecting their actual condition scores compared to that of their reference state (assuming no pristine ecosystem)
	Ecosystem asset	5	Credit	Hectare	A (Statement of Biodiversity Position)	
Recording condition-adjusted losses and gains associated to existing ecosystem asset condition scores	Periodic losses	5	Debit	Hectare equivalent	Z (Statement of Biodiversity Performance)	Mandatory re-adjustment for all new ecosystem assets, reflecting actual loss of ecosystem of maximum potential condition (reference state) and the associated accumulated negative impacts and periodic gains linked to the initial/baseline ecosystem assets
	Accumulated negative impacts	Any, except 5	Credit	Hectare equivalent	C (Statement of Biodiversity Position)	
	Periodic gains	Any, except 5	Credit	Hectare equivalent	Y (Statement of Biodiversity Performance)	
Accounting for changes in ecosystem condition (losses)	Ecosystem asset	Inferior to the one of the account credited just below	Debit	Hectare	A (Statement of Biodiversity Position)	Required to record changes in the condition of ecosystem assets of the same type, since similar ecosystem assets are segregated according to their condition scores
	Ecosystem asset	Superior to the one of the account debited just above	Credit	Hectare	A (Statement of Biodiversity Position)	
	Periodic losses	Same as the one of the account credited above for this event	Debit	Hectare equivalent	Z (Statement of Biodiversity Performance)	
	Accumulated negative impacts	Same as the one of the account credited above for this event	Debit	Hectare equivalent	C (Statement of Biodiversity Position)	
	Accumulated negative impacts	Same as the one of the account debited above	Credit	Hectare equivalent	C (Statement of Biodiversity Position)	
Accounting for changes in ecosystem condition (gains)	Ecosystem asset	Superior to the one of the account credited below	Debit	Hectare	A (Statement of Biodiversity Position)	Required to record changes in the condition of ecosystem assets of the same type, since similar ecosystem assets are segregated according to their condition scores
	Ecosystem asset	Inferior to the one of the account debited above	Credit	Hectare	A (Statement of Biodiversity Position)	
	Accumulated negative impacts	Same as the one of the account credited just above	Debit	Hectare equivalent	C (Statement of Biodiversity Position)	
	Accumulated negative impacts	Same as the one of the account debited above for this event	Credit	Hectare equivalent	C (Statement of Biodiversity Position)	
	Periodic gains	Same as the one of the account debited above for this event	Credit	Hectare equivalent	Y (Statement of Biodiversity Performance)	
Closing the Statement of Biodiversity Performance	Net ecosystem impact	None	Debit	Hectare equivalent	X (Statement of Biodiversity Performance)	Mandatory to complete the Statement of Biodiversity Position
	Accumulated positive impacts	Any, accounts disaggregated	Credit	Hectare equivalent	B (Statement of Biodiversity Position)	

Table 4
Summary of condition scores of ecosystem assets and the associated positive and negative impacts at each key event of the NMR train station case study.

NMR Train station		Condition rating of Garrigue-type ecosystems (Ha eq.)						
Accounting events	Accounts	0	1	2	3	4	5	Total
Reference state	Ecosystem account (Ha) (A)	0.00	0.00	0.00	0.00	0.00	26.11	26.11
	Associated positive impacts (Ha eq.) (B)	0.00	0.00	0.00	0.00	0.00	26.11	26.11
	Associated negative impacts (Ha eq.) (C)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Changes (Ha Eq.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Prior to development	Ecosystem account (Ha) (A)	15.16	10.95	0.00	0.00	0.00	0.00	26.11
	Associated positive impacts (Ha eq.) (B)	0.00	2.19	0.00	0.00	0.00	0.00	2.19
	Associated negative impacts (Ha eq.) (C)	15.16	8.76	0.00	0.00	0.00	0.00	23.92
	Changes (Ha Eq.)	0.00	2.19	0.00	0.00	0.00	−26.11	−23.92
After development (residual impacts)	Ecosystem account (Ha) (A)	26.11	0.00	0.00	0.00	0.00	0.00	26.11
	Associated positive impacts (Ha eq.) (B)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Associated negative impacts (Ha eq.) (C)	26.11	0.00	0.00	0.00	0.00	0.00	26.11
	Changes (Ha Eq.)	0.00	−2.19	0.00	0.00	0.00	0.00	−2.19
After offset measures	Ecosystem account (Ha) (A)	26.11	27.00	0.00	0.00	0.00	0.00	53.11
	Associated positive impacts (Ha eq.) (B)	0.00	5.40	0.00	0.00	0.00	0.00	5.40
	Associated negative impacts (Ha eq.) (C)	26.11	21.60	0.00	0.00	0.00	0.00	47.71
	Changes (Ha Eq.)	0.00	5.40	0.00	0.00	0.00	0.00	5.40

3.1. The statements of biodiversity position and performance of the NMR train station

Applying new conventions to DEBK to account for the ecosystem impacts of the NMR train station project led to the recording of accounting journal entries that satisfy both the Statements of Biodiversity Position and Performance equations. Results are presented in the following tables:

- Table 4 summarises the condition scores of the different accounts at each key event for the NMR train station project;
- Table 5 presents all the accounting journal entries for the NMR train station case study, at each key event of the project;
- Table 6 shows the associated Statement of Biodiversity Performance and
- Table 7 shows the corresponding Statement of Biodiversity Position.

The recording of events through the adaptation of DEBK can be explained as follows:

- First, it is critical to account for the reference state (original or pristine condition, as per expert assessment) of the ecosystem assets to be acquired for development as it underpins all future changes in ecosystem extent and condition scores: i.e. debiting ecosystem(s) account(s) of condition 5 by 26.11 Ha (A account) and crediting maximum potential gains of 26.11 Ha eq. (Y account) (journal entry 1).
- Prior to development, the condition rating of scrub habitats (Côteaux de Jonquières Saint-Vincent) was assessed to be 1 (see Table 4) for 10.95 Ha and 0 for 15.16 Ha. Accordingly, this leads to the following journal entries, as detailed in Table 5:
  - o Journal entry 2: Debiting ecosystem accounts reflecting actual condition scores of 0 (15.16 Ha) and 1 (10.95 Ha) and crediting ecosystem account of condition 5 (26.11 Ha) (all A accounts);
  - o Journal entry 3: Debiting losses of ecosystem of condition 5 (26.11 Ha eq.) (Z account) and crediting the accumulated negative impacts (15.16 Ha eq. and 8.76 Ha eq. respectively) (C accounts) and periodic gains (2.19 Ha eq.) (Y account) of the ecosystem assets of condition 0 and 1.
- After development, the whole 26.11 Ha will be urbanised. This implies that all ecosystem assets will now have a condition score of 0, hence the need to debit the ecosystem of condition 0 by a further 10.95 Ha and to credit the ecosystem of condition 1 by the same amount (all A accounts) (journal entry 4). Because ecosystem assets of condition score 0 do not have positive impacts (see Tables 1 and 4), periodic losses of 2.19 Ha eq. (Z account) are recorded as well as the associated changes in accumulated impacts due to the new ecosystem condition scores (i.e. debiting 8.76 Ha eq. of condition 1 and crediting 10.95 Ha eq. of condition 0) (C accounts) (journal entry 5).
- After offset measures, new ecosystem assets need to be accounted for. This involves first recording their reference state (debit 27,00 Ha of condition 5 – A account, credit 27.00 Ha eq. of gains – Y account) (journal entry 6) and then readjusting for their actual condition scores (debit 27.00 Ha of condition 1 – A account, credit 27.00 Ha of condition 5 – A account) (journal entry 7) and the associated periodic losses (debit 27.00 Ha eq. of condition 5 – Z account), periodic gains (credit 5,40 Ha eq. of condition 1 – Y account) and accumulated negative impacts (credit 21,60 Ha eq. of condition 1 – C account) (journal entry 8).
- Finally, to complete the Statement of Biodiversity Position, the statement of Biodiversity Performance needs to be closed: i.e. debiting net impacts (X account) by 5.40 Ha eq. and crediting the corresponding accumulated positive impacts of condition 1 by 5.40 Ha eq. (B account) (journal entry 9).

Table 6 presents the Statement of Biodiversity Performance of the NMR train station case study, listing the individual gains and losses linked to changes in both the extent and condition of ecosystem accounts.

Table 7 presents the Statement of Biodiversity Position of the NMR train station project, in surface area metrics and in percentage, the latter showing the proportion of accumulated positive (5,40 Ha eq. or 10% of ecosystem assets) and negative impacts (47,71 Ha eq. or 90% of ecosystem assets).

Adapting DEBK to biodiversity impact accounting thus enables the accounting of both the extent and condition of ecosystem impacts at the level of the NMR train station project. This differs from project-level net impact assessment (as required by law) where the land footprint is often overlooked or forgotten. With respect to the planned offset measures for the NMR train station project, it is important to note that these were designed to offset the loss of habitats for a selection of threatened species (i.e. these were not designed as offsets for ecosystem or vegetation/habitat loss). When data on populations of species is lacking or limited, environmental impact assessors often use habitat extent and quality/condition as a proxy for species occurrence. In our case, only the results of the adaptation of DEBK to ecosystem impact accounting is shown. In practice, the actual performance of the offset measures

Table 5
Accounting journal entries to produce the Statements of Biodiversity Position and Performance for the NMR train station case study.

Journal entries	Accounting events	Account	Account category	Condition score	DR	CR
1	Accounting for reference state of ecosystem assets to be developed, which underpins their subsequent condition scoring	Ecosystem asset (Ha)	A (Statement of Biodiversity Position)	Garrigue-type condition 5	26.11	
1		Periodic gains (Ha eq.)	Y (Statement of Biodiversity Performance)	Garrigue-type condition 5		26.11
(a) Prior to development						
2	Stock tacking, recording ecosystem assets according to their condition scores	Ecosystem asset (Ha)	A (Statement of Biodiversity Position)	Garrigue-type condition 0	15.16	
2		Ecosystem asset (Ha)	A (Statement of Biodiversity Position)	Garrigue-type condition 1	10.95	
2		Ecosystem asset (Ha)	A (Statement of Biodiversity Position)	Garrigue-type condition 5		26.11
3	Recording condition-adjusted losses and gains associated to existing ecosystem asset condition scores	Periodic losses (Ha eq.)	Z (Statement of Biodiversity Performance)	Garrigue-type condition 5	26.11	
3		Accumulated negative Impacts (Ha eq.)	C (Statement of Biodiversity Position)	Garrigue-type condition 0		15.16
3		Accumulated negative Impacts (Ha eq.)	C (Statement of Biodiversity Position)	Garrigue-type condition 1		8.76
3		Periodic gains (Ha eq.)	Y (Statement of Biodiversity Performance)	Garrigue-type condition 1		2.19
(b) after development (residual impacts)						
4	Recording ecosystem assets according to changes in their condition scores	Ecosystem asset (Ha)	A (Statement of Biodiversity Position)	Garrigue-type condition 0	10.95	
4		Ecosystem asset (Ha)	A (Statement of Biodiversity Position)	Garrigue-type condition 1		10.95
5	Recording condition-adjusted losses and gains associated to changes in ecosystem asset condition scores	Periodic losses (Ha eq.)	Z (Statement of Biodiversity Performance)	Garrigue-type condition 1	2.19	
5		Accumulated negative Impacts (Ha eq.)	C (Statement of Biodiversity Position)	Garrigue-type condition 1	8.76	
5		Accumulated negative Impacts (Ha eq.)	C (Statement of Biodiversity Position)	Garrigue-type condition 0		10.95
(c) After offset measures						
6	Accounting for reference state of new ecosystem assets purchased as part of offset measures, which underpins their subsequent condition scoring	Ecosystem asset (Ha)	A (Statement of Biodiversity Position)	Garrigue-type condition 5	27.00	
6		Periodic gains (Ha eq.)	Y (Statement of Biodiversity Performance)	Garrigue-type condition 5		27.00
7	Recording ecosystem assets according to their condition scores	Ecosystem asset (Ha)	A (Statement of Biodiversity Position)	Garrigue-type condition 1	27.00	
7		Ecosystem asset (Ha)	A (Statement of Biodiversity Position)	Garrigue-type condition 5		27.00
8	Recording condition-adjusted losses and gains associated to new ecosystem asset condition scores	Periodic losses (Ha eq.)	Z (Statement of Biodiversity Performance)	Garrigue-type condition 5	27.00	
8		Accumulated negative Impacts (Ha eq.)	C (Statement of Biodiversity Position)	Garrigue-type condition 1		21.60
8		Periodic gains (Ha eq.)	Y (Statement of Biodiversity Performance)	Garrigue-type condition 1		5.40
9	Closing the Statement of Biodiversity Perfomance	Net impact (Ha eq.)	X (Statement of Biodiversity Performance)	Net impacts	5.40	
9		Accumulated positive Impacts (Ha eq.)	B (Statement of Biodiversity Position)	Garrigue-type condition 1		5.40

Table 6
Statement of Biodiversity Performance (X = Y – Z) for the NMR train station case study.

Journal entries	Periodic gains (Y)		Hectares equivalents (Ha eq.)
1	Accounting for reference state of ecosystem assets to be developed, which underpins their subsequent condition scoring	Garrigue-type condition 5	26,11
3	Before development, recording gains associated to existing ecosystem asset condition scores	Garrigue-type condition 1	2,19
6	Accounting for reference state of new ecosystem assets purchased as part of offset measures, which underpins their subsequent condition scoring	Garrigue-type condition 5	27,00
8	After offset measures, recording condition-adjusted gains associated to new ecosystem asset condition scores	Garrigue-type condition 1	5,40
		Sub-total periodic gains (Y)	**60,70**
Journal entries	**Periodic losses (Z)**		**Hectares equivalents (Ha eq.)**
3	Before development, recording losses associated to existing ecosystem asset condition scores	Garrigue-type condition 5	26,11
5	After development, recording condition-adjusted losses associated to changes in ecosystem asset condition scores	Garrigue-type condition 1	2,19
8	After offset measures, recording condition-adjusted losses associated to new ecosystem asset condition scores	Garrigue-type condition 5	27,00
		Sub-total periodic losses (Z)	**55,30**
		Net ecosystem impacts (X = Y - Z)	**5,40**

should be assessed and disclosed on a regular basis, as biodiversity and habitats may change over time. Indeed, it is critical to evaluate and record whether and when the proposed outcomes of the offset do eventuate.

3.2. *The statements of biodiversity position and performance of the cossure offset project*

Applying new conventions to DEBK to account for the ecosystem impacts of the Cossure offset project led to the recording of accounting journal entries that satisfy both the Statements of Biodiversity Position and Performance equations. Results are presented in the following tables:

- Table 8 summarises the condition scores of the different ecosystem accounts at each key event of the Cossure offset project;
- Table 9 presents all the accounting journal entries for the Cossure offset case study, at each key event of the project;
- Table 10 shows the associated Statement of Biodiversity Performance and
- Table 11 shows the corresponding Statement of Biodiversity Position.

These accounting events can be explained as follows:

- First, as for the NMR train station case study, it is critical to account for the reference state (original or pristine condition, as per expert assessment) of the ecosystem assets to be acquired for development as it underpins all future changes in ecosystem extent and condition scores and enables the adaptation of double-entry bookkeeping: i.e. debiting ecosystem(s) account(s) of condition 5 by 357.00 Ha (A account) and crediting maximum potential gains by 357.00 Ha eq. (Y account) (journal entry 10).
- On purchase, the actual condition rating of the Coussoul habitat was assessed to be 0 as the 357 Ha were irrigated fruit orchards. This requires the following journal entries, as detailed in Table 9:
  - Journal entry 11: Debiting ecosystem account of condition 0 (357.00 Ha) and crediting ecosystem account of condition 5 (357.00 Ha) (all A accounts);
  - Journal entry 12: Debiting losses of ecosystem of condition 5 (357.00 Ha eq.) (Z account) and crediting the accumulated negative impacts (357.00 Ha eq.) (C account) of the ecosystem asset of condition 0;
- After the completion of the restoration measures, the following journal entries are warranted:
  - Recording the changes in the condition of ecosystem assets: i.e. debiting ecosystem accounts of condition 2 (273 Ha) and 3 (84 Ha) and crediting the ecosystem account of condition 0 (357 Ha) (all A accounts) (journal entry 13);
  - Recording the associated decrease in accumulated negative impacts of ecosystem of condition 0 (debiting 357 Ha eq.; C account), periodic gains of ecosystem accounts of condition 2 and 3 (i.e. crediting them by 163.80 Ha eq. and 33.60 Ha eq. respectively; Y accounts), and increases in accumulated negative impacts of ecosystem accounts of condition 2 and 3 (crediting them by 109.20 Ha eq. and 50.40 Ha eq. respectively; C accounts) (journal entry 14);
- Finally, to complete the Statement of Biodiversity Position for the

Table 7
Statement of Biodiversity Position (A = B + C) for the NMR train station case study.

Assets (A)			**Accumulated negative impacts (C)**		
Ecosystem accounts	Hectares (Ha)	Percentage (%)	Ecosystem accounts	Hectares equivalents (Ha eq.)	Percentage (%)
			Garrigue-type condition 0	26,11	49%
			Garrigue-type condition 1	21,60	41%
			Accumulated positive impacts (B)		
Garrigue-type condition 0	26,11	49%	Ecosystem accounts	Hectares equivalents (Ha eq.)	Percentage (%)
Garrigue-type condition 1	27,00	51%	Garrigue-type condition 1	5,40	10%
Total	**53,11**	100%	**Total**	**53,11**	100%

Table 8
Summary of condition scores of ecosystem assets and the associated positive and negative impacts at each key event of the Cossure offset case study.

Cossure offset project		Condition rating of "Coussoul" habitat						
Accounting events	Accounts	0	1	2	3	4	5	Total
Reference state	Ecosystem account (Ha) (A)	0.00	0.00	0.00	0.00	0.00	357.00	357.00
	Associated positive impacts (Ha Eq.) (B)	0.00	0.00	0.00	0.00	0.00	357.00	357.00
	Associated negative impacts (Ha Eq.) (C)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Changes (Ha Eq.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Prior to land purchase	Ecosystem account (Ha) (A)	357.00	0.00	0.00	0.00	0.00	0.00	357.00
	Associated positive impacts (Ha Eq.) (B)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Associated negative impacts (Ha Eq.) (C)	357.00	0.00	0.00	0.00	0.00	0.00	357.00
	Changes for stage (Ha Eq.)	0.00	0.00	0.00	0.00	0.00	−357.00	−357.00
After purchase	Ecosystem account (Ha) (A)	357.00	0.00	0.00	0.00	0.00	0.00	357.00
	Associated positive impacts (Ha Eq.) (B)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Associated negative impacts (Ha Eq.) (C)	357.00	0.00	0.00	0.00	0.00	0.00	357.00
	Changes for stage (Ha Eq.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
After restoration measures	Ecosystem account (Ha) (A)	0.00	0.00	273.00	84.00	0.00	0.00	357.00
	Associated positive impacts (Ha Eq.) (B)	0.00	0.00	109.20	50.40	0.00	0.00	159.60
	Associated negative impacts (Ha Eq.) (C)	0.00	0.00	163.80	33.60	0.00	0.00	197.40
	Changes for stage (Ha Eq.)	0.00	0.00	109.20	50.40	0.00	0.00	159.60

Cossure offset project, the Statement of Biodiversity Performance needs to be closed: i.e. debiting net impacts (X account) by 159.60 Ha eq. and crediting the corresponding accumulated positive impacts of condition 2 and 3 by 109.20 Ha eq. and 50.40 Ha eq. respectively (B accounts) (journal entry 15).

Table 10 presents the Statement of Biodiversity Performance of the Cossure offset case study, listing the individual gains and losses linked to changes in both the extent and condition of ecosystem accounts.

Table 11 presents the Statement of Biodiversity Position of the Cossure offset project, in surface area metrics and in percentage, the latter showing the proportion of negative impacts (197,40 Ha eq. or 55% of ecosystem assets) and accumulated positive (159,60 Ha eq. or 45% of ecosystem assets).

Proposing new conventions to DEBK for biodiversity impact accounting thus allows to account for changes in both the extent and condition of ecosystem at the level of the Cossure offset project, highlighting how ecological restoration measures have significantly increased (by 45%) the condition score of the ecosystem assets (from an initial condition score of 0). However, the reference state (score of 5) of the Cossure habitat has yet to be reached, which may not be possible (Tatin et al., 2013; Helm et al., 2019) and might require further restoration research and/or activities.

3.3. Aggregating project or site level data and its implications for corporate accounting and disclosure

Assuming the two projects belong to the same company (which is not the case), our biodiversity-specific conventions to DEBK allow for the scaling up of project-level data and the aggregation of ecosystem assets and associated accumulated negative and positive impacts at the company level. Table 12 shows the aggregated Statement of Biodiversity Position for the NMR train station and Cossure offset projects, with a resulting total of 410,11 Ha of ecosystem assets (A accounts), 165 Ha eq. of accumulated positive impacts (B accounts) and 245,11 Ha eq. of accumulated negative impacts (C accounts). By including the whole Cossure offset property, the company has increased its share of accumulated positive biodiversity impacts to 40% of total ecosystem assets owned (compared to 10% when only looking at the NMR case study). While the underlying accounts for each ecosystem type and associated condition scores remain distinct (securing the incommensurability of biodiversity components for net impact accounting), due to the adaptation of DEBK principles, this approach allows reporting organisations to compile and disclose their global ecosystem impacts across sites, biomes and nations. This means that companies can set condition-improvement targets for their ecosystem assets, both individually and globally, for instance in the context of corporate no net loss and net positive impact biodiversity commitments for the post-2020 global biodiversity framework of the Convention on Biological Diversity (de Silva et al., 2019; Bull et al., 2019; Meinard et al., 2019). Securing ecosystems of high or pristine condition (e.g., through the creation of new private protected areas) could be a 'quick' option to improve their proportion of accumulated positive impacts to accumulated negative impacts at the corporate level.

Reporting organisations may use Statements of Biodiversity Performance and Position as key performance indicators, in quantitative, non-monetary terms, for sustainability and integrated reporting. From an integrated reporting perspective (i.e. disclosure of forward-looking plans or targets), the reporting organisations may also disclose expected future ecosystem impacts or expected ecosystem gains/losses according to planned activities (e.g., restoration of plant communities within a property, plans for offset property purchase, sale of land assets).

3.4. Implications for financial accounting

Because these project-level data are drawn from permitting processes, they can have financial implications, for instance due to project closure or offset requirements set by the relevant permitting authorities. For the NMR train station, offset property acquisition costs were estimated to be €100 000 while monitoring and management costs were assessed to be around €62 000 (Biotope 2017). An overall €12,5M were purportedly invested in the purchase, restoration and management of the Cossure offset project, at an approximate average cost of €35 000 per hectare (Dutoit et al., 2015). Such information may also be disclosed by reporting organisations and may help build the business case for biodiversity. At the project and corporate levels, projections may be made showing potential future ecosystem asset scenarios, the associated negative and positive impacts and the associated financial liabilities and/or associated savings due to impact avoidance measures.

3.5. Methodological limitations and future work

First, two concerns may arise from our proposed changes to conventional DEBK. These interconnected issues relate to the use of different (non-financial) metrics and account terminologies (e.g., no liability and owner's equity accounts). While critics may argue that the use of non-financial metrics is counterproductive for business decision-

Table 9
Accounting journal entries to produce the Statements of Biodiversity Position and Performance for the Cossure offset case study.

Journal entries	Accounting events	Account	Account category	Condition score	DR	CR
10	Accounting for reference state of ecosystem assets, which underpins their subsequent condition scoring	Ecosystem asset (Ha)	A (Statement of Biodiversity Position)	Coussoul condition 5	357.00	
10		Periodic gains (Ha eq.)	Y (Statement of Biodiversity Performance)	Coussoul condition 5		357.00
(a) On purchase						
11	Stock tacking of ecosystem assets, according to their condition scores	Ecosystem asset (Ha)	A (Statement of Biodiversity Position)	Coussoul condition 0	357.00	
11		Ecosystem asset (Ha)	A (Statement of Biodiversity Position)	Coussoul condition 5		357.00
12	Recording condition-adjusted losses and gains associated to existing ecosystem asset condition scores	Periodic losses (Ha eq.)	Z (Statement of Biodiversity Performance)	Coussoul condition 5	357.00	
12		Accumulated negative Impacts (Ha eq.)	C (Statement of Biodiversity Position)	Coussoul condition 0		357.00
(b) After restoration measures						
13	Recording ecosystem assets according to changes in their condition scores	Ecosystem asset (Ha)	A (Statement of Biodiversity Position)	Coussoul condition 2	273.00	
13		Ecosystem asset (Ha)	A (Statement of Biodiversity Position)	Coussoul condition 3	84.00	
13		Ecosystem asset (Ha)	A (Statement of Biodiversity Position)	Coussoul condition 0		357.00
14	Recording condition-adjusted losses and gains associated to newecosystem asset condition scores	Accumulated negative Impacts (Ha eq.)	C (Statement of Biodiversity Position)	Coussoul condition 0	357.00	
14		Accumulated negative Impacts (Ha eq.)	C (Statement of Biodiversity Position)	Coussoul condition 2		163.80
14		Accumulated negative Impacts (Ha eq.)	C (Statement of Biodiversity Position)	Coussoul condition 3		33.60
14		Periodic gains (Ha eq.)	Y (Statement of Biodiversity Performance)	Coussoul condition 2		109.20
14		Periodic gains (Ha eq.)	Y (Statement of Biodiversity Performance)	Coussoul condition 3		50.40
15	Closing the Statement of Biodiversity Perfomance	Net impact (Ha eq.)	X (Statement of Biodiversity Performance)	Net impacts	159.60	
15		Accumulated positive Impacts (Ha eq.)	B (Statement of Biodiversity Position)	Coussoul condition 2		109.20
15		Accumulated positive Impacts (Ha eq.)	B (Statement of Biodiversity Position)	Coussoul condition 3		50.40

Table 10
Statement of Biodiversity Performance (X = Y – Z) for the Cossure offset case study.

Journal entries	Periodic gains (Y)		Hectares equivalents (Ha (eq.)
1	Accounting for reference state of ecosystem assets on purchase, which underpins their subsequent condition scoring	Coussoul condition 5	357.00
5	After restoration measures, recording condition-adjusted gains associated to new ecosystem asset condition scores	Coussoul condition 2	109.20
5	After restoration measures, recording condition-adjusted gains associated to new ecosystem asset condition scores	Coussoul condition 3	50.40
Sub-total periodic gains (Y)			**516.60**
Journal entries	Periodic losses (Z)		Hectares equivalents (Ha (eq.)
3	On purchase of ecosystem assets, recording condition-adjusted losses associated to existing ecosystem asset condition scores	Coussoul condition 5	357.00
Sub-total periodic losses (Z)			**357.00**
Net ecosystem impacts (X = Y – Z)			**159.60**

making purposes, we would support Farrell's (2007, p. 14) argument that "*monetary unit-based environmental valuation methods are counter-productive to their own purpose of 'taking the economic worth of un-priced environmental goods and service into account.' … It is suggested that, in lieu of monetary valuation, taking the economic worth of these phenomena into account may be better served by focusing efforts on the design of new value articulation methods that are capable of expressing their priceless economic worth.*" Our views are also in line with the plurality of values and valuation approaches supported by IPBES (Díaz et al., 2015; Pascual et al., 2017). Although our approach accounts only for physical changes of ecosystem assets (in hectare), information generated by its application can be used in economic valuation exercises, especially non-market valuation techniques that aim to assess people's willingness-to-pay for the improved conditions of ecosystem assets.

With respect to the use of different account terminologies, we would highlight that:

- Liability accounts convey the message that the organisation has to settle the debt due to contractual obligations, which is not necessarily the case for all biodiversity impacts as only a subset of ecosystems may have a mandatory requirement to be restored (e.g., no-net-loss requirements for a project). Activities which lead to net positive impacts would be voluntary in most cases (management's decision).
- Equity/capital accounts imply the concept of profit-making, which does not exist in our adaptation of DEBK for net biodiversity impact accounting. No financial-like profits are feasible in biodiversity accounting due to (a) the lack of financial transactions and (b) the finite nature of ecosystem assets. As discussed previously, the maximum value of ecosystem assets (in hectares) will always equal the maximum positive biodiversity impact possible (in hectares equivalents) in relation to the selected physical ecosystem boundary. It cannot exceed it.

Furthermore, when assessing the condition or quality of impacted habitats, it is worth emphasising the importance of making use of the most suitable biodiversity expertise. There are different generally accepted condition-scoring methodologies for different ecosystem types (e.g., unique methodologies for wetlands) and countries (reflecting both the spatial heterogeneity of biodiversity and different perceptions of nature). This means assessing cover type against a reference or benchmark, which can be either a target or a past "pristine" or "natural" state (i.e. without human impacts) which may not always be known, understood or agreed upon, hence the need to ensure transparency regarding the assumptions and estimations made (Ureta et al., 2020).

For instance, Europe holds mostly transformed ecosystems so that experts may have limited knowledge of their original or reference condition or quality and may tend to overestimate the condition of ecosystem in largely transformed landscapes. This is particularly important when monitoring changes in condition over time, for instance to ensure that the consequences of any management activity aimed at improving habitat quality or condition can be measured against a comparable baseline. In addition, caution is advised when using vegetation structure and composition to reflect habitat condition as this may mask other important ecosystem-level factors (e.g., Wawrzyczek et al., 2018).

It is also vital to ensure that experts provide further description and associated quantification for condition ratings of different habitat types being assessed. This helps ensure that linguistic uncertainty associated with qualitative descriptions of condition categories, and experts own subjective bias in interpreting condition categories and actual habitat condition, is minimised (Martin et al., 2012). To guard even more against subjective bias and uncertainty associated with condition assessments undertaken by individual experts, groups of experts can be asked to make individual condition assessments and the average or mode of assessments can then be taken for the final condition

Table 11
Statement of Biodiversity Position (A = B + C) for the Cossure offset case study.

Assets (A)			Accumulated negative impacts (C)		
Ecosystem accounts	Hectares (Ha)	Percentage (%)	Ecosystem accounts	Hectares equivalents (Ha eq.)	Percentage (%)
			Coussoul condition 2	163,80	46%
			Coussoul condition 3	33,60	9%
			Accumulated positive impacts (B)		
			Ecosystem accounts	Hectares equivalents (Ha eq.)	Percentage (%)
Coussoul condition 2	273,00	76%	Coussoul condition 2	109,20	31%
Coussoul condition 3	84,00	24%	Coussoul condition 3	50,40	14%
Total	**357,00**	100%	**Total**	**357,00**	100%

Table 12
Aggregated Statement of Biodiversity Position for the ecosystem impacts of the two case studies.

Assets (A)			Accumulated negative impacts (C)		
Ecosystem accounts	Hectares (Ha)	Percentage (%)	Ecosystem accounts	Hectares equivalents (Ha eq.)	Percentage (%)
			Garrigue-type condition 0	26,11	6%
Garrigue-type condition 0	26,11	6%	Garrigue-type condition 1	21,60	5%
			Coussoul condition 2	163,80	40%
Garrigue-type condition 1	27,00	7%	Coussoul condition 3	33,60	8%
			Accumulated positive impacts (B)		
Coussoul condition 2	273	67%	Ecosystem accounts	Hectares equivalents (Ha eq.)	Percentage (%)
			Garrigue-type condition 1	5,40	1%
Coussoul condition 3	84,00	20%	Coussoul condition 2	109,20	27%
			Coussoul condition 3	50,40	12%
Total	**410,11**	**100%**	**Total**	**410,11**	**100%**

assessment (Burgman et al., 2011; Burgman et al., 2014).

While the adaptation of DEBK has been applied to account for net impacts on ecosystems, future work might focus on exploring:

- Net impacts on taxa, using both population-based and surface-area based methods to assess changes in population sizes or areas of occupancy;
- Indirect and cumulative net biodiversity impacts, whilst taking into account the implications of the apportionment of responsibilities amongst companies and other agents involved;
- The in-depth documentation and review of condition scoring systems worldwide, towards the possible standardisation of approaches where possible and warranted (e.g., for similar ecosystems in different countries);
- Net impacts on other forms of natural capital stocks and flows, such as water quantity and quality, sequestered carbon, etc;
- Net impacts beyond direct operations (gate-to-gate), including upstream (cradle-to-gate) and downstream (gate-to-grave) impacts;
- The development of a full chart of accounts associated to the various areas for further research listed previously;
- The potential to embed land cover data (e.g., GIS data on ecosystem extent and condition) in XBRL, or eXtensible Business Reporting Language, an XML standard for tagging business and financial reports to increase the transparency and accessibility of information by using a uniform format;
- The potential to use these new conventions of DEBK in the context of Experimental Ecosystem Accounting under the national System of Environmental-Economic Accounting (SEEA-EEA), for example as a framework for business data inputs associated to the development of national ecosystem extent and condition accounts.

In time, the need to adopt standardised methodologies for assessing net impacts on different forms of natural capital cannot be over-emphasised. The Biological Diversity Protocol[8] (BD Protocol; Endangered wildlife Trust EWT, 2020), which is currently in development, is such an attempt. For the purpose of this BD Protocol, biodiversity accounting refers to the process of identifying, measuring, recording, summarising and reporting the biodiversity impacts of an organisation resulting from operations over a period of time. The BD Protocol further defines biodiversity impact, or impact on biodiversity, as the negative or positive effect of any business activity on biodiversity, with two main types of biodiversity components recognised: land cover types (i.e. habitat, ecosystem or vegetation type, as recognised by applicable laws or authorities) and taxa (i.e. species, sub-species). Our proposed adaptation of DEBK to biodiversity is compatible with the BD Protocol.

[8] Version for consultation accessed on January 13, 2020 at URL: http://www.bdprotocol.org/bdp-protocol.php,

4. Conclusion

This paper has provided case study illustrations of the adaptation of double-entry bookkeeping to enable corporate net biodiversity impact accounting and disclosure. The proposed adjusted DEBK allows companies to track and aggregate ecosystem impacts, both positive and negative, over time and across different sites. The ensuing Statements of Biodiversity Position and Performance show consolidated impact data which are useful to both internal and external stakeholders in order to make informed decisions. By keeping comprehensive records of net impacts on biodiversity over time, DEBK can help stakeholders better understand whether management activities are effective in reaching corporate biodiversity targets. While this research provides a solid accounting foundation for use in future corporate biodiversity impact disclosure, it also opens new avenues for the use of DEBK in corporate sustainability accounting and reporting, notably for other forms of natural capital stocks and flows. To that end, a key challenge would be the development of new adaptations of DEBK that would make net impact assessment methodologies and metrics compatible.

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.

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