From Footprints to Handprints? Principles for Assessing an Organisation's Positive Impacts on Biodiversity

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SUMMARY

Organisations are a major driver of biodiversity loss, but may also have positive impacts on biodiversity. Limited guidance exists for how positive biodiversity impacts should be quantified, presenting a risk to organisations and biodiversity more widely. Here we introduce the 'biodiversity handprint' framework, enabling organisations to measure and communicate the additional positive contributions that they create for biodiversity beyond the mitigation of their own footprint. We establish ten guiding principles for assessing biodiversity handprints, building upon previous literature on environmental handprints and biodiversity offsetting. Overall, biodiversity handprints can be a useful tool for organisations to assess and report their positive impacts, albeit with large uncertainties. While biodiversity handprints may motivate and support progress towards global biodiversity goals, management of negative biodiversity impacts remains paramount.

Keywords: Biodiversity handprint; biodiversity footprint; carbon handprint; biodiversity loss; biodiversity offsetting.

INTRODUCTION

Human-driven biodiversity loss is eroding ecosystem integrity, destabilizing the biophysical foundations of human well-being and threatening the viability of global economies and societal stability[1–3]. Organisations are increasingly recognizing their responsibility to halt and reverse this decline, driven by ambitious international commitments such as those articulated in the Global Biodiversity Framework [4–6]. A key avenue for action is the avoidance and mitigation of negative biodiversity impacts, many of which are embedded within complex, globalized value chains[7–10]. In this context, biodiversity footprinting has emerged as a leading approach for systematically quantifying and reporting negative organisational impacts within value chains[11]. When integrated with the mitigation hierarchy, footprinting guides the prioritization of concrete actions to reduce biodiversity loss [12].

The central role of the mitigation of negative impacts is well established: without decisive actions, bending the curve of biodiversity loss remains unattainable[13]. At the same time, a growing number of businesses and other organisations are seeking to understand and demonstrate the positive biodiversity impacts of their actions and products[14–16]. Emphasising positive impacts may be particularly effective in incentivising organisational change, complementing approaches that focus primarily on reducing harm. However, in contrast to better established approaches for quantifying and reporting negative biodiversity impacts, methods for systematically quantifying and reporting positive contributions remain underdeveloped[17,18].

When credibly measured and communicated, the positive biodiversity impacts of organisations can enable more sustainable consumer choices, attract investments into biodiversity-beneficial activities, inform organisational sustainability strategies, and mobilise private finance towards biodiversity-enhancing services and products[19,20]. More fundamentally, achieving global ambitions for nature requires moving beyond no net loss towards measurable net positive outcomes for biodiversity, representing a transformative change from reducing impacts and offsetting harm to actively restoring and regenerating ecosystems[21–23]. Reflecting this shift, initial efforts to quantify and report positive biodiversity impacts are emerging across sectors, including impact investing, product innovation, and academia[14,24–26].

The absence of a generally accepted framework for quantifying and reporting positive biodiversity impacts represents a major obstacle for organisations[27]. This challenge is further amplified by the complexity of increasingly global value chains through which biodiversity impacts (positive and

negative) arise, making robust quantification and attribution of positive impacts difficult[17,28]. In the absence of coherent guidance on positive impacts, organisations may develop heterogeneous, non-comparable methodologies or refrain from reporting positive impacts altogether - a practice increasingly referred to as greenhushing [28,29]. Conversely, weak safeguards can create incentives for selective disclosure of positive impacts for impression management purposes, and mask the substantial negative impacts generated by organisations[30–32]. The lack of guidance also presents risks to businesses: reported positive impacts that do not reflect genuine biodiversity gains risk undermining organisational credibility through accusations of greenwashing while legitimising biodiversity loss[33]. Despite initial advances to clarify the scenarios in which positive actions arise[15,17], there remains no coherent and widely accepted approach for the credible quantification and reporting of positive biodiversity impacts.

As biodiversity is increasingly mainstreamed in business decision-making [34], this represents a critical moment to scrutinise how and under what conditions positive biodiversity impacts should be assessed and claimed by organisations. Here, we develop a conceptual and methodological foundation for organisations to assess such positive impacts. We begin by outlining how organisations can drive positive biodiversity impacts, which are often excluded from traditional biodiversity assessment frameworks or broader biodiversity goals. We then introduce the 'biodiversity handprint' framework as a solution to assessing positive biodiversity impacts. We build upon the concept of environmental and social 'handprints', originally used in environmental education and later formalised in environmental impact literature to characterize the environmental benefits of products, services, or organisations, with most applications to date focusing on carbon[18,35]. We provide a set of ten guiding principles for organisations to credibly assess and report their biodiversity handprints, outlining key practical considerations for their implementation. Finally, we discuss how biodiversity handprints can support organisational action aligned with broader biodiversity ambitions, including nature positive goals[36].

ORGANISATIONS AS A DRIVER OF POSITIVE BIODIVERSITY IMPACTS

The role of organisations as a driver of global biodiversity loss is well established, prompting major efforts to quantify, mitigate and offset organisational biodiversity impacts[7,37]. At the same time, organisations are increasingly recognising their role in generating positive biodiversity impacts, through investments and research, for example[25,38]. To date, however, business and biodiversity literature has focused on the role of organisations in reducing negative impacts via the mitigation hierarchy[39,40], or on organisations that deliver positive impacts via traditional land conservation or

management[19]. Little attention has been given towards positive biodiversity impacts that can theoretically arise from an organisation's actions within and beyond their value chain[14,24–26]. Building on the environmental handprint literature, we propose that actions driving positive biodiversity impacts can be classified four distinct categories: innovation, initiative, investment, and additional conservation actions (Box 1).

Innovation refers to development of products, services, or practices that contribute to handprints through the reduction of pressures on biodiversity of other organisations and individuals. For example, a company may produce plant-based meat alternatives that facilitate reduction in meat consumption and associated pressures to biodiversity[20]. Second, initiatives encompass actions that promote behavioural change and enable other actors to undertake biodiversity-beneficial actions. Examples of initiatives include promoting of pro-environmental behaviours in communities, or conducting research and teaching to support sustainability action [25,41]. Third, investments in innovations or initiatives that reduce biodiversity pressures or improve the state of biodiversity through the actions of other actors (e.g. through investing in projects that deliver biodiversity positive products or interventions[42,43]). Fourth, additional conservation actions such as restoration or protection generate positive biodiversity outcomes, both within and beyond the value chain, therefore improving the state of biodiversity outside the scope of mitigating an organisation's own impacts. For example, organisations may donate to conservation organisations or establish protected areas, alongside actions that adhere to the mitigation hierarchy[15]. However, actions that drive positive biodiversity impacts may fall into several categories. Buying protected areas, for example, represents both an investment and an additional conservation action.

Positive biodiversity impacts are typically excluded from traditional biodiversity assessment frameworks, despite the large number of actions that could generate positive outcomes (Box 1)[15,17,14,24–26]. Initial approaches to characterise positive biodiversity impacts are mostly qualitative, focusing on the scenarios in which positive actions arise, and the role of organisations in producing biodiversity 'solutions' [15,17,44,45]. Existing quantitative approaches focus on individual drivers of biodiversity loss, including land use change[46] and carbon[18,28]. A further challenge lies in how organisations should report their positive impacts. To date, limited guidance for how an organisation's positive impacts could contribute to wider biodiversity objectives. The lack of guidance on the contribution of positive impacts towards biodiversity goals is problematic, as positive actions could facilitate the transformative changes needed to achieve nature positive[20,47].

Box 1. Examples of organisations driving positive biodiversity impacts

(i) **Innovation:** An organisation may create products, services, or practices that enable other actors to reduce their biodiversity impacts. Examples include commodity replacements such as ALTEX, which produces textiles from food waste, and Modern synthesis, which makes novel fabrics using bacteria, can reduce the biodiversity impact of the global textile trade. Innovations in alternative food sources can further reduce land use pressures compared to conventional commodities, with examples including alternative proteins from Beyond Meat and NotCo, and cocoa substitutes produced by Planet A Foods[19,42]. Innovations may also facilitate more effective conservation outcomes, for example through improved monitoring technology. Examples include NatureMetrics[43], providing eDNA services, and rePLANET[44], which specialises in large-scale nature restoration and biodiversity monitoring.

(ii) **Initiative:** Organisations may undertake actions that encourage behaviour change in other actors, generating positive biodiversity outcomes. Media organisations may drive pro-environmental behaviours due to their reporting of conservation issues, for example through the BBC's Natural History Unit[51] or the Guardian's climate and nature journalism[52]. Universities can drive positive biodiversity impacts through their research and teaching, as demonstrated by the quantified positive environmental impacts of MIT's Sustainability Lab course[24]. Organisations can also lobby for biodiversity-friendly policies, such as the UK Green Building Council's advocacy for Biodiversity Net Gain [47].

(iii) **Investment:** Organisation may allocate financial resources to support innovations or initiatives that reduce the biodiversity impacts of other actors, or improve the state of biodiversity elsewhere. Corporate funding for conservation is one approach to drive positive impacts, such as Patagonia's 1% for the Planet pledge[48] and Kering's Regenerative Fund for Nature. Investments may also support biodiversity innovations and initiatives, for example venture capital firms Agronomic and CPT Capital investing in alternative protein technology. Impact investing mechanisms such as green and blue bonds may also be used to direct money into conservation efforts, such as the Wildlife Conservation Bond[40,41,49].

(iv) **Additional conservation actions:** Organisation may undertake actions intended to benefit biodiversity that are not linked to its own negative impacts. For example, renewable companies have undertaken extensive blanket bog restoration on windfarm sites (Scottish Renewables, Vattenfall)[50], and established wildflower meadows around solar farms (Eden Renewables). Organisations may also undertake land or sea- scale restoration beyond their regulatory requirements. Materials company Holcim, for example, has committed to freshwater ecosystem restoration beyond the boundaries of their site[51]. Establishing a protected area may also drive positive biodiversity impacts for an organisation, as shown by Nokia's nature conservation areas in Finland[52].

THE BIODIVERSITY HANDPRINT FRAMEWORK

Here, we propose the use of 'biodiversity handprints' as a framework for organisations to credibly assess and report their positive impacts on biodiversity. Biodiversity handprints refer to an actor's demonstrable and additional positive contributions to biodiversity, beyond the mitigation of their own footprint[48]. Handprints often materialise through influences across and beyond an organisation's value chain[17,49–51]. Biodiversity handprints may occur either through reducing pressures on biodiversity caused by other individuals or organisations, or through directly improving the state of biodiversity – from actions beyond mitigation of an organisation's own biodiversity footprint.

Firstly, biodiversity handprints can occur due to reductions in pressure when an organisation's actions influence upstream, downstream, or beyond value chain actors, thereby reducing the biodiversity footprint of other organisations or individuals. Handprints in this category include innovative products or services that allow customers to reduce their biodiversity impacts, or investments into biodiversity innovations (Box 1). Importantly, impact reductions considered as a handprint must not overlap with reductions to the focal organisation's own footprint. Such impacts should be understood as mitigation within the organisation's own system boundary (Box 2), rather than as additional benefits that constitute biodiversity handprints.

Secondly, biodiversity handprints may result from actions that improve the state of biodiversity, such as ecosystem restoration or conservation interventions[15]. Examples handprints include initiatives that encourage others to undertake pro-environmental behaviours, or carrying out additional conservation actions, such as establishing protected areas (Box 1). In many cases, these impacts are mediated through complex causal pathways, including behavioural change among other actors, making attribution inherently challenging. Importantly, these actions can only be considered handprints if they are not explicitly used to mitigate an organisation's own negative impacts as part of the mitigation hierarchy (Box 2).

Biodiversity handprints are conceptually distinct from biodiversity offsets. Offsets are designed to compensate for negative impacts in accordance with the mitigation hierarchy[13,21]. In comparison, handprints refer to additional actions to generate positive biodiversity outcomes, which are not used to mitigate an organisation's own negative impacts under the mitigation hierarchy. This distinction is fundamental, as handprints shift the focus from compensating harm to creating positive biodiversity contributions. In practice, however, distinguishing between actions to mitigate an organisation's

negative impacts and actions that represent a handprint is not always clear-cut and requires careful consideration of system boundaries i.e., the scope of impacts an organisation is including within their own footprint as part of their strategy (Box 2)[17,52]. We comment upon the role of handprints in comparison to offsets in greater detail within the Outlook section.

Box 2. System boundaries for biodiversity handprints

Biodiversity handprints arise from actions that occur beyond the direct mitigation of an organisation's own biodiversity footprint. In practice, however, determining which impacts can be attributed to an organisation's own footprint- and where organisations have a responsibility to reduce harm- is not always straightforward[17].

Limited traceability and transparency in global supply chains can constrain attributing impacts to different actors, and biodiversity impacts may be driven by historical actions, making attribution more challenging[17,53,54]. Responsibility for negative impacts is increasingly understood as shared among value chain actors[55]. Organisations may hold different perspectives and cultural values regarding whether a negative impact falls within their responsibility to reduce, even if an impact is attributable to their actions[56].

Here we recommend that organisations take responsibility, at a minimum, for the most immediate actors in their value chain. Responsibility could be proportional to the share of the actor's annual expenses or production attributable to the organisation. For example, if an organisation purchases one-fifth of a supplier's total output, then they should be responsible for one-fifth of the supplier's negative impacts[57]. However, greater levels of responsibility including full value chain responsibility are assumed by frameworks such as the GHG protocol and TNFD[58,59]. Transparency in value chains is expected to improve over time, for example through regulatory developments and digital traceability technologies[60], enabling increasingly robust methods for attribution of responsibility[41]. Clearly defining system boundaries and actor responsibilities is a critical prerequisite for designing effective biodiversity strategies [16], and the credible assessment of handprints.

QUANTIFYING BIODIVERSITY HANDPRINTS

The biodiversity handprint framework provides a means to credibly quantify and report positive contributions towards biodiversity. We illustrate approaches to quantifying different types of handprints in Figure 1. Handprints may arise from reducing pressures on biodiversity caused by other actors (Figure 1a), or from additional conservation actions that directly improve the state of biodiversity, provided they are not explicitly linked to mitigating the organisation's own impacts (Figure 1b). Importantly, generating a biodiversity handprint does not eliminate the original biodiversity impact of the focal organisation. Therefore, handprints and footprints should be reported separately.

Figure 1(a): Handprint generated from reducing an external actor's biodiversity impacts.

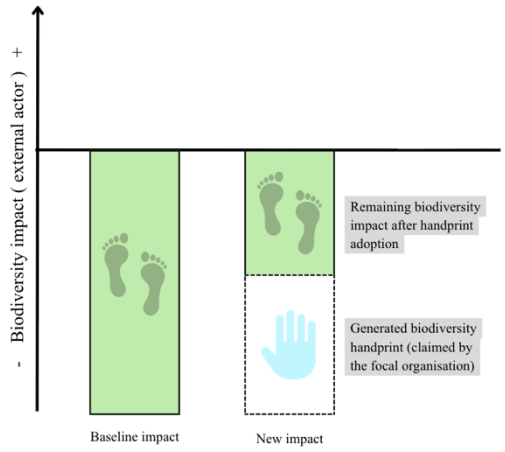


Figure 1(b): Handprint generated from additional conservation actions not linked to mitigating the focal organisation's impacts.

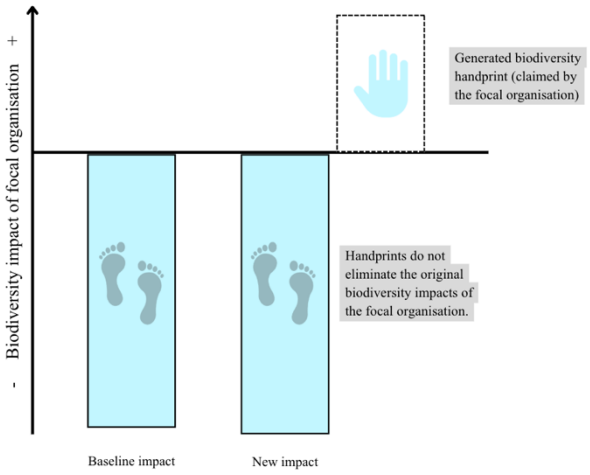


Figure 1: Quantifying biodiversity handprints, from the perspective of a focal organisation. *Biodiversity handprints can be quantified in terms of how much they reduce the biodiversity footprint of upstream, downstream, or beyond value chain actors ('external actors') (Figure 1a). Handprints may also undertake additional conservation actions not directly linked to mitigating the focal organisation's own impacts (Figure 1b). However, generating handprints does not eliminate the original biodiversity impacts of the focal organisation.*

Quantifying handprints requires comparison against a robust counterfactual scenario in which the action did not occur, ensuring outcomes can be credibly attributed to the specific intervention [53,54]. Comparison against a counterfactual scenario can be methodologically challenging as biodiversity handprints can arise from physical products as well as from more abstract ideas and practices. There is likely a scale of feasibility in identifying and quantifying positive actions for biodiversity.

Quantifying handprints for innovations that demonstrate a clear increase in energy or material efficiency, and therefore reductions in other individual or organisations biodiversity impacts, for example, may be relatively straightforward [14]. The handprint of additional conservation actions or investments may also be feasible to quantify, although constrained by the selection of appropriate counterfactuals and impact metrics [15,42,43,55]. Quantifying positive outcomes from initiatives such as research or promotion of pro-environmental behaviours is particularly challenging. Initial attempts to quantify positive impacts have been undertaken in a university context at MIT, however, where the outcomes of a project-based sustainability course were quantified using the University handprint framework[48].

Here, we recommend that actions that are not quantifiable should be excluded from reporting of biodiversity handprints, as they do not represent a demonstrable positive contribution to biodiversity. However such actions may still be worthwhile for biodiversity, and may be reported qualitatively [44,56]. As impact evaluation methodologies develop, it is likely that a greater number of actions can be quantified according to the handprint framework, while ensuring integrity of the handprint concept.

GUIDING PRINCIPLES FOR BIODIVERSITY HANDPRINT ASSESSMENT

Despite growing interest and emerging applications, robust guidance for assessing biodiversity handprints remains underdeveloped. In particular, the quantification and attribution of positive biodiversity impacts are subject to significant methodological challenges, creating risks of inconsistent, non-comparable, or potentially misleading claims[31]. Without clear guiding principles, handprint assessments risk undermining both scientific credibility and organisational accountability.

The concept of handprints has been extensively used in the climate domain to describe the positive contributions an actor can make to reduce GHG emissions[18]. However, approaches to quantify climate handprints cannot be directly cannot be directly transferred to biodiversity. For one, broad consensus and standardisation has been established for carbon impact assessment.-with consistent reporting using the CO_2 equivalent (CO_2e) metric[57]. In comparison, biodiversity outcomes are inherently location-specific and shaped by multiple interacting drivers of biodiversity loss. Biodiversity impact assessment lack a standardised link to global biodiversity loss, and cannot be described through a single metric [58], although efforts for more standardised approaches are progressing [8,59]. Reducing biodiversity to a limited set of indicators and interpretating values from aggregated results risks delivering unintended outcomes for conservation, such as displacement of biodiversity impacts [60–62].

Accordingly, the principles presented here draw on both the literature on avoided biodiversity impacts [63] and prior work on carbon handprints[64–67].

We propose ten principles[64] to guide the credible assessment and reporting of biodiversity handprints (Figure 2). These principles operationalise the concepts of system boundaries, additionality, mechanisms, and attribution introduced above, and aim to ensure that reported positive impacts are transparent, robust, and comparable across contexts. Detailed guidance is provided for each of the ten principles (Table 1).

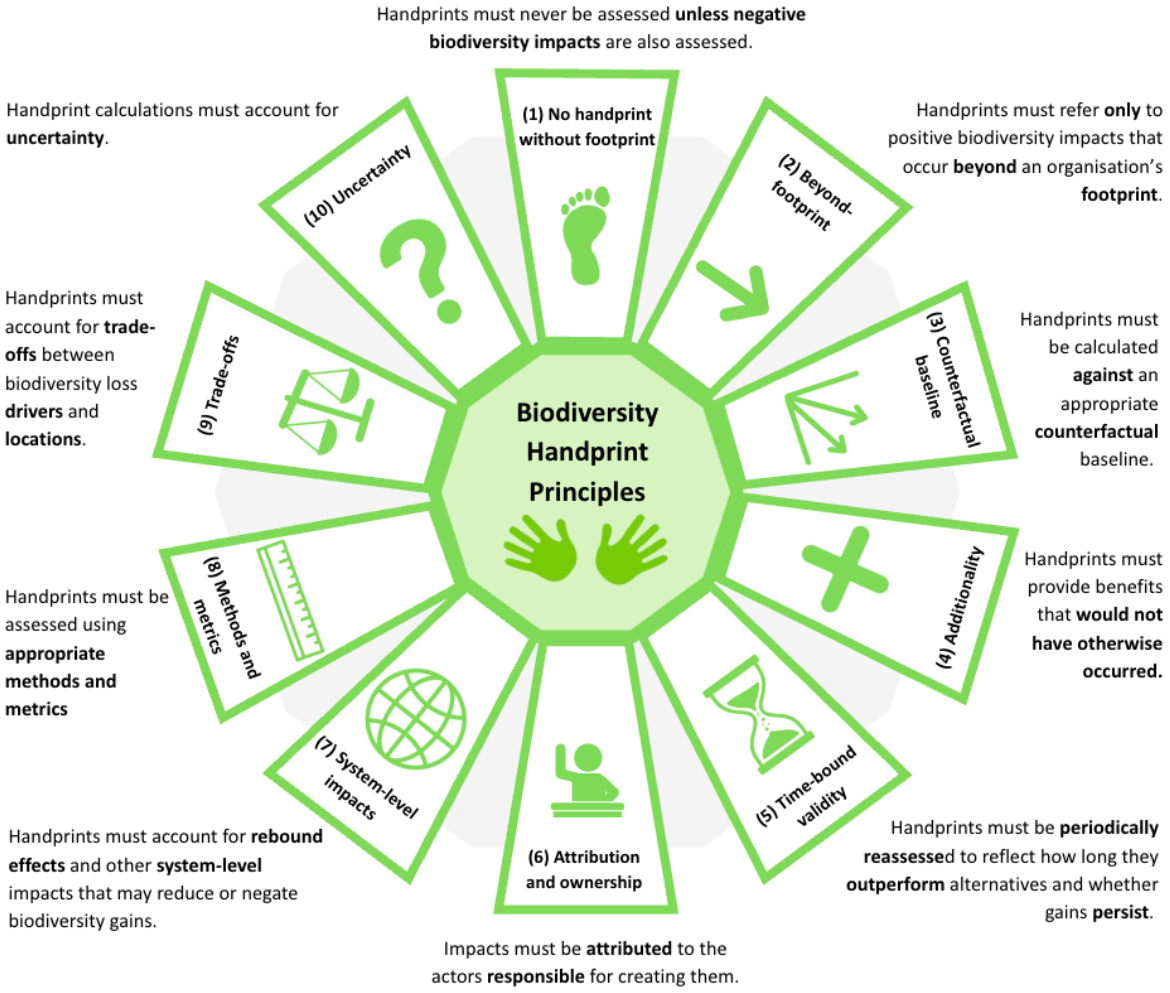


Figure 2: Ten guiding principles for assessing biodiversity handprints. *Building upon the principles for Nature Positive (figure based upon Principles for Nature Positive, White et al.[36], following Booth et al. [68]).*

Principle		Guidance
1.	**No handprint without footprint**: Handprints must never be assessed or reported unless negative biodiversity impacts are concurrently assessed and reported.	Organisations must assess and report their negative biodiversity impacts (their footprints) before conducting any handprint assessment. Footprints and handprints must be reported separately to maintain transparency and avoid conflation. Handprints must complement, not replace, the quantification and reporting of negative impacts, ensuring that positive contributions are communicated only alongside a clear and complete account of an organisation's biodiversity responsibilities.
2.	**Beyond-footprint**: Handprints must refer only to positive biodiversity impacts that occur beyond an organisation's footprint and are additional to addressing those impacts.	Beyond an organisation's footprint means outside the scope of its own negative biodiversity impacts across local operations and the value chain. Positive impacts qualify as handprints only if they do not mitigate the organisation's negative impacts, but instead deliver additional biodiversity benefits elsewhere (see Box 2). This distinction prevents double counting between footprint reduction and handprint claims.
3.	**Counterfactual baseline**: Handprints must be calculated against an appropriate counterfactual baseline.	The counterfactual baseline must be evidence-based and transparently documented, clearly indicating what would have occurred in the absence of the actions that benefitted biodiversity. It should be independently verified to ensure credibility and prevent inappropriate or inflated claims[61]. The counterfactual should be periodically reviewed and updated to remain relevant over time, ensuring that handprint estimates continue to reflect genuine additional biodiversity benefits (see also principle 5).
4.	**Additionality**: Handprints must provide benefits that would not have otherwise occurred.	Actions generating handprints must go beyond legal, regulatory, or compliance requirements and exceed what would be achieved through business-as-usual practices (i.e. a causal additionality condition).
5.	**Time-bound validity**: Handprints must be periodically reassessed to reflect how long they outperform alternatives and remain in use (innovations) and whether gains persist.	Handprints do not always represent permanent positive impacts. For innovations, validity depends on how long the underlying innovation continues to outperform relevant alternatives and remains adopted in practice [69]. As these conditions change over time, the magnitude and relevance of handprints may decline or cease. Other types of handprints maintain validity for as long as their gains persist. Handprints must be reassessed at appropriate intervals.
6.	**Attribution and ownership:** Impacts must be attributed to	Handprints should be attributed to the actors that ideate, produce or carry out the action generating the positive impacts [28], while responsibility for negative biodiversity impacts (footprint) remains

	the actors responsible for creating them.	with those that cause them. Where multiple actors contribute, shared ownership may be appropriate, but allocation must be clearly justified to avoid overlap or double counting.
7.	**System-level impacts:** Handprints must account for rebound effects and other system-level impacts that may reduce or negate expected biodiversity gains.	Handprints are subject to rebound effects, where actions that reduce pressures on biodiversity may fail to deliver expected gains or even increase impacts at the system level [70]. Such outcomes are analogous to leakage effects observed in biodiversity offsetting [63]. For example, efficiency improvements can make resource use cheaper and more widespread (Jevon's Paradox), potentially increasing total pressure on biodiversity [71]. Organisations should identify and transparently report such system-level risks to ensure credible handprint claims.
8.	**Methods and metrics:** Handprints must be assessed using appropriate methods and metrics that are transparently documented.	Given the lack of fully standardized approaches for measuring biodiversity impacts, organisations should apply methods and metrics that reflect current best practice and are appropriate to the assessment context. This includes using up-to-date data, clearly justified methodological choices, and frameworks aligned with recognized initiatives[72,73].
9.	**Trade-offs across drivers and locations**: Handprint calculations must account for trade-offs between biodiversity loss drivers and locations.	Biodiversity loss arises from multiple drivers [68]. Handprints may deliver biodiversity gains by reducing pressures from one driver or in one location while increasing or shifting pressures elsewhere. Positive impacts must not come at the cost of hidden or displaced harms and should be managed through safeguards [75].
10.	**Uncertainty**: Handprint calculations must account for uncertainty.	Handprint assessments involve significant uncertainties, particularly when modelling avoided future biodiversity impacts. Organisations should identify, document, and transparently report key sources of uncertainty, including assumptions, data limitations, and methodological choices [76]. Uncertainty multipliers should be applied to explicitly account for uncertainty and prevent overestimation of biodiversity gains.

Table 1: The ten principles and guidance for assessing biodiversity handprints.

PRACTICAL CONSIDERATIONS FOR BIODIVERSITY HANDPRINT ASSESSMENT

Ensuring handprints contribute towards global biodiversity goals requires not only clear principles but also their effective application in organisational practice. Building on the principles outlined in the previous section, (Table 1) here we highlight key considerations for implementing biodiversity handprint assessments.

A fundamental prerequisite is the comprehensive assessment of an organisation's biodiversity footprint (Principle 1). In practice, this requires clearly defining and justifying system boundaries for both footprint and handprint assessments. Without transparent scoping, there is a risk that organisations overemphasise positive contributions by comparing them to only a subset of their negative impacts. For example, a university may highlight the handprint generated through its sustainability research [14], yet such contributions must be contextualised against potentially substantial value chain impacts generated by the research activities [7,8]. To maintain credibility, footprint and handprint results must be reported separately and interpreted in conjunction.

A second key challenge lies in distinguishing between mitigation versus genuinely additional positive contributions outside the scope of organisation's own negative biodiversity impacts (Principle 2). In practice, organisations must clearly articulate how specific actions generate biodiversity benefits beyond addressing their own impacts. This distinction can be particularly ambiguous for innovations that simultaneously reduce an organisation's own footprint and influence other actors [16,47,77]. While such innovations may contribute to mitigation, only effects that reduce the impacts of external actors or create additional benefits beyond mitigation of the organisation's own footprint constitute handprint contributions. Robust quantification of handprints requires comparison to an appropriate counterfactual scenario, ensuring the principles of additionality are met (Principle 3 & 4) [77,78] . This often involves comparing handprint-generating products or services to realistic market alternatives [28]. Existing datasets, such as Environmental Product Declarations, can support such comparisons, while consequential Life Cycle Assessment methods may be used for more abstract handprint activities, including behavioural or policy influence and advocacy [80,81]. Given the centrality of counterfactual assumptions, transparency and independent verification are critical to ensure credibility [13,54,82].

Ensuring that handprints remain additional over time introduces further complexity (Principle 5). Biodiversity benefits of innovations are inherently dynamic as market conditions and technological

baselines evolve. As a result, handprints are time-bound and may diminish or cease as alternatives improve, or the innovation no longer represents an improvement against market averages [69]. Organisations should therefore estimate and report the expected duration of handprints using average innovation and adoption lifespans for a particular product, service or practice, a practice similar to the generation of response curves in biodiversity offsetting [13,83]. Handprints arising from other types of actions may maintain their additionality over longer periods, depending on the persistence of the intervention and counterfactual conditions.

Attribution presents another practical challenge, particularly in complex value chains where responsibility is distributed across multiple actors (Principle 6). While double counting of negative impacts may not pose a risk for biodiversity, overlapping claims of positive impacts does. Simultaneously, overlapping of handprint claims undermines both the credibility of an organisation's actions and the principle of additionality for positive impacts[13]. Organisations should therefore clearly define ownership of handprints, attribute impacts to the actors enabling them, and transparently communicate any shared contributions [84]. This may be challenging in practice, so it should be clearly stated what boundaries are being used for handprint assessments, and where overlaps may be possible.

At the system level, biodiversity handprints may generate unintended consequences (Principle 7). For instance, efficiency improvements can trigger rebound effects, increasing overall resource use and undermining biodiversity gains, analogous to leakage effects observed in biodiversity offsetting [63]. One mechanism for this is Jevon's paradox, where efficiency gains reduce costs and stimulate increased consumption [71]. While such dynamics are difficult to quantify, organisations should identify and transparently disclose potential system-level risks, take action to reduce these risks, and reflect them in counterfactual assumptions and reporting [85].

The selection of appropriate methods and metrics remains a major implementation challenge (Principle 8)[86,87]. In the absence of standardised approaches, organisations must rely on best available science and emerging frameworks such as the Nature Positive Initiative [73] and Taskforce on Nature-related Financial Disclosures[72]. Life cycle–based approaches, including Life Cycle Impact Assessment, offer a promising avenue for capturing impacts across value chains and multiple drivers of biodiversity loss [88,89]. However, their application is often constrained by data limitations and uncertainty [76]. In such cases, pressure-based indicators (e.g. water use or greenhouse gas emissions) may provide a pragmatic, interim alternative for estimating positive impacts, provided their limitations are clearly acknowledged. These approaches are also important for identifying and

managing trade-offs across drivers and locations [75], a focal consideration in organisational risk management (Principle 9).

Uncertainty is inherent to biodiversity assessments, particularly where impacts are indirect or modelled, as is likely the case for many handprinting actions (Principle 10). Sources of uncertainty include data gaps, model assumptions, and the complex multidimensional nature of biodiversity itself [76,90,91]. Organisations should explicitly account for uncertainty through transparent documentation, for example through the use of uncertainty multipliers. Transparent reporting and clear communication of results is central for assessing biodiversity handprints, in line with the above principles. Choices of system boundaries, counterfactual scenarios, assessment methods, metrics, and attribution of responsibility must be clearly documented, well-defined and evidence based. Communicating methodological choices, limitations and uncertainties alongside handprint results is essential for maintaining credibility and enabling informed interpretation.

In practice, organisations will typically generate handprints through multiple actions rather than a single action. These can be assessed individually and either aggregated or reported separately, depending on context. However, aggregation must be approached cautiously to avoid inappropriate comparisons with overall biodiversity impacts, reinforcing the importance of maintaining a clear distinction between footprint and handprint reporting.

OUTLOOK

ADVANCING GLOBAL BIODIVERSITY GOALS

Biodiversity handprints provide a promising approach for organisations to explicitly capture their positive contributions towards biodiversity, a necessary step in meeting the targets of the Global Biodiversity Framework (Target 15). Yet, their utility in advancing global biodiversity goals remains contingent on how they are applied in practice. Importantly, handprints are not an alternative to mitigating biodiversity footprints, but a constrained and complementary mechanism to recognise an organisation's additional positive contributions to biodiversity beyond mitigation of their own footprint. In this sense, handprints reframe organisational impacts from impact minimisation or offsetting towards a more proactive logic of enabling positive change.

This shift does not diminish the central importance of mitigating negative biodiversity impacts. Reducing negative biodiversity impacts remains the primary pathway through which organisations contribute to global biodiversity goals [6,21,36,39]. Biodiversity handprints do not address an

organisation's own impacts and are therefore insufficient on their own to halt and reverse biodiversity loss [54]. Rather, the importance of handprints lies in incentivising systemic change in organisations. These actions, seen alongside other actions linked to negative impacts, can help corporations develop a biodiversity strategy aligned with global biodiversity goals[17]. In this role, biodiversity handprints can complement mitigation by expanding the scope and scale of organisational action.

The effectiveness of biodiversity handprints is nevertheless constrained by broader system dynamics. Efficiency improvements enabled by handprint-generating actions may be negated by increasing levels of consumption, thereby limiting overall biodiversity gains. This highlights the importance of complementing handprints with policies that address sufficiency and the overall level of consumption in societies [92,93]. Without such integration, handprints could risk reinforcing relative improvements without achieving absolute reductions in pressures on biodiversity.

HANDPRINTS AS A COUNTERBALANCING MECHANISM

An important question concerns how biodiversity handprints could contribute to balancing organisational impacts, particularly those embedded within global value chains (Figure 3). Global value chain impacts are challenging to address via traditional biodiversity offsetting due to their strict ecological requirements, but a need for compensation remains [13,31,59]. Biodiversity handprints may be used by organisations to 'counterbalance' their global value chain impacts, provided the stringent methodological and governance conditions formulated here are met (Figure 3) [17,31]. In particular, their use for counterbalancing impacts would require robust demonstration of additionality, clearly defined and independently verified counterfactuals, transparent attribution of impacts, and careful consideration of temporal and spatial equivalence between gains and losses. Importantly, handprints do not eliminate the underlying biodiversity harm generated by an organisation, highlighting the essential role of mitigation in addressing biodiversity loss (Figure 3).

Figure 2: Handprints as an approach for counterbalancing organisational footprints

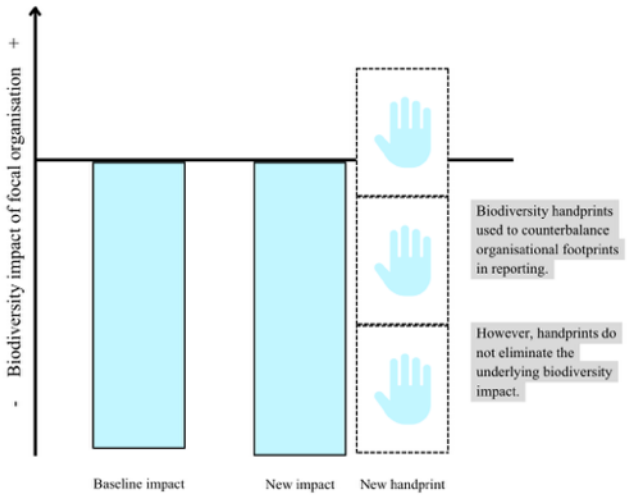


Figure 3: Biodiversity handprints as an approach for counterbalancing organisational footprints*, from the perspective of the organisation generating the handprint ('focal organisation'). While biodiversity handprints may be used to counterbalance negative impacts, particularly within global value chains ('New handprint'), such accounting does not itself eliminate the underlying biodiversity harm ('New impact').*

Importantly, handprints should remain conceptually distinct from biodiversity offsets. Although some actions to generate a handprint- undertaking habitat restoration, for example- may be similar to those that produce an offset, they occur in different contexts [13,82]. Traditional biodiversity offsets fall within the mitigation hierarchy, and typically compensate for direct impacts in known locations [13,59]. In comparison, actions that generate a biodiversity handprint cannot contribute to the mitigation hierarchy and instead may 'counterbalance' impacts across global value chains (Figure 3). Separate accounting and safeguards are therefore necessary to prevent double counting of positive actions, while acknowledging that both mechanisms play an important role to address biodiversity loss.

NEXT STEPS FOR BIODIVERSITY HANDPRINTS

The biodiversity handprint framework presented here provides a useful framing to help guide, quantify and report positive actions for biodiversity. To help reach global biodiversity goals, organisations must mitigate negative impacts, whilst also contributing to proactive positive action – where the handprint framework can help catalyse action.

The next step for handprints requires detailed testing of the framework in different organisational and sectoral contexts, to identify pathways for implementation and to identify the best tools, metrics and methodologies for reporting.

There are challenges here that need to be overcome. For example, quantifying changes in biodiversity is technically demanding, requires high quality data, appropriate methods and metrics, and explicit treatment of uncertainty, all of which may currently be beyond the capacity of many organisations [76]. This creates both practical and reputational risks, as poorly substantiated claims of positive biodiversity impacts may lead to accusations of greenwashing [29,94,95]. Methodological and data related progress is imperative, and is already taking place [17,76]. Case studies to quantify biodiversity handprints of organisations will also play a key role; the most promising of these is likely innovations which replace commodities and reduce pressures on biodiversity, such as food substitutes[19,46,96]. We recommend that pilots take place across sectors and handprint-generating actions, alongside trialling different methods for quantifying impact.

Overall, the handprint framework can help corporations report on their positive impacts across different scales and actors, alongside the suite of actions at different scales required for corporations to contribute to a nature positive future[17,68]. While the handprint framework focuses on positive impacts, it also draws attention to the negative impacts that organisations may have beyond their conventional footprint boundaries. Organisations may drive biodiversity loss indirectly through activities such as lobbying to weaken social or environmental legislation, or through marketing shaping consumption patterns [7,32,64,97,98]. Conceptualising such negative biodiversity impacts as an additional, system-level footprints could broaden current assessment frameworks and facilitate transformative change for organisations. Applying the same principles to negative impacts would improve consistency between handprints and footprints, but raises additional methodological challenges.

Overall, the biodiversity handprint framework represents a useful tool for organisations to assess and report their positive impacts. The credibility of handprints depends on their rigorous application and clear separation from footprint mitigation. The role of handprints in advancing nature-positive outcomes will depend on continued methodological development and their integration within broader governance frameworks.

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Author contributions

Maddinson, C. and Pykäläinen, E., jointly co-ordinated the project and drafted the manuscript. Figures were produced by Maddinson, C. All authors contributed to the conceptual development of the manuscript, and provided input and reviews to all drafts.

References

1. Dasgupta, D. *The Economics of Biodiversity: The Dasgupta Review*. https://www.gov.uk/government/publications/final-report-the-economics-of-biodiversity-the-dasgupta-review (2021).
2. WEF. *The Global Risks Report 2026*. https://www.weforum.org/publications/global-risks-report-2026/ (2026).
3. IPBES. Global Assessment Report on Biodiversity and Ecosystem Services | IPBES secretariat. https://www.ipbes.net/node/35274 (2019).
4. CBD. COP 15: Final text of Kumning-Montreal Global Biodiversity Framework. (2022).
5. Addison, P. F. E., Bull, J. W. & Milner-Gulland, E. J. Using conservation science to advance corporate biodiversity accountability. *Conserv. Biol.* **33**, 307–318 (2019).
6. Locke, H. *A Nature-Positive World: The Global Goal for Nature*. (2020).
7. Bull, J. W. *et al.* Analysis: the biodiversity footprint of the University of Oxford. *Nature* **604**, 420–424 (2022).
8. El Geneidy, S., Peura, M., Baumeister, S. & Kotiaho, J. Value-transforming financial, carbon and biodiversity footprint accounting. https://arxiv.org/abs/2309.14186 (2026).

9. Panwar, R. Business and biodiversity: achieving the 2050 vision for biodiversity conservation through transformative business practices. *Biodivers. Conserv.* **32**, 3607–3613 (2023).
10. Peura, Sami El Geneidy, Krista Pokkinen, Veera Vainio, & Janne S. Kotiaho. Väliraportti: S-ryhmän luontojalanjälki. 1–45 (2023) doi:10.17011/jyureports/2023/20.
11. De Ryck, J., Driesen, K., Verhelst, J. & Lammerant, J. Assessment of Biodiversity Measurement Approaches for Businesses and Financial Institutions, Update Report 5 on behalf of the EU Business & Biodiversity Platform. (2024).
12. White, T. B. *et al. Using Life Cycle Assessment as Part of Robust Biodiversity Strategy Design*. https://naturerecovery.ox.ac.uk/outputs/using-life-cycle-assessment-as-part-of-robust-biodiversity-strategy-design/ (2025).
13. Moilanen, A. & Kotiaho, J. S. Fifteen operationally important decisions in the planning of biodiversity offsets. *Biol. Conserv.* **227**, 112–120 (2018).
14. Burek, J. *et al.* Assessing handprint potentials for business's eco-innovation. *Sustain. Prod. Consum.* **29**, 201–214 (2022).
15. Leitch, L. *et al. Navigating Additional Conservation Actions for Nature Positive Contributions*. https://zenodo.org/records/20082439 (2026) doi:10.5281/zenodo.20082439.
16. Liu, J. & Tu, Y. Green Innovation and Biodiversity Conservation: Evidence from the Yangtze River Economic Belt. *Sustainability* **18**, 1915 (2026).
17. Bang, A. H. Y. *et al.* A Typology of Corporate Actions for a Nature-Positive Future. https://ecoevorxiv.org/repository/view/10429/ (2025).
18. Vatanen, S. *et al. The Carbon Handprint Approach to Assessing and Communicating the Positive Climate Impact of Products. VTT Technical Research Centre of Finland, VTT Technology 346. Vatanen, S., Pajula, T., Grönman, K., Behm, K., Kasurinen, H., Soukka, R., Leino, M., & Hohenthal, C.* https://publications.vtt.fi/pdf/technology/2018/T346.pdf (2018).
19. Zu Ermgassen, S. O. S. E. *et al.* Business models for biodiversity. (2026).

20. Egli, F., Martin, R., Wildgruber, K., zu Ermgassen, S. & Chapman, M. Mobilising private finance for biodiversity. *Preprint* (2026).
21. Milner-Gulland, E. J. Don't dilute the term Nature Positive. *Nat. Ecol. Evol.* **6**, 1243–1244 (2022).
22. Milner-Gulland, E. J. *et al.* Four steps for the Earth: mainstreaming the post-2020 global biodiversity framework. *One Earth* **4**, 75–87 (2021).
23. Victurine, R. *et al.* Nature Positive mining: Guidance for a critical transition. *PLOS Sustain. Transform.* **3**, e0000142 (2024).
24. Asselin, A. *et al.* Product Biodiversity Footprint – A novel approach to compare the impact of products on biodiversity combining Life Cycle Assessment and Ecology. *J. Clean. Prod.* **248**, 119262 (2020).
25. Burek, J. *et al.* University handprint framework: quantifying the positive impacts of university-led sustainability action research. *Int. J. Sustain. High. Educ.* https://doi.org/10.1108/IJSHE-10-2024-0755 (2025) doi:10.1108/IJSHE-10-2024-0755.
26. Lhoest, S., Carr Kelman, C., Barton, C. J., Beaudette, J. A. & Gerber, L. R. The impact factor of engaged research: Metrics for conservation outcomes. *Biol. Conserv.* **292**, 110534 (2024).
27. Elliot, V., Jonäll, K., Paananen, M., Bebbington, J. & Michelon, G. Biodiversity reporting: standardization, materiality, and assurance. *Curr. Opin. Environ. Sustain.* **68**, 101435 (2024).
28. Russell, S. Estimating and Reporting the Comparative Emissions Impacts of Products. https://www.wri.org/research/estimating-and-reporting-comparative-emissions-impacts-products (2019).
29. Hilton, J. An integrated analysis of greenhush. *Innov. Green Dev.* **4**, 100222 (2025).
30. Blanco-Zaitegi, G., Álvarez Etxeberria, I. & Moneva, J. M. Impression management of biodiversity reporting in the energy and utilities sectors: An assessment of transparency in the disclosure of negative events. *J. Behav. Exp. Finance* **42**, 100942 (2024).

31. Durand, M., White, T., Bromwich, T., zu Ermgassen, S. O. S. E. & Martinet, V. Challenges and pathways for matching corporate value-chain biodiversity losses and gains. https://doi.org/hal-05122951 (2025) doi:hal-05122951.
32. Folke, C. *et al.* Transnational corporations and the challenge of biosphere stewardship. *Nat. Ecol. Evol.* **3**, 1396–1403 (2019).
33. Guillaume, J. H. A. *et al.* Giving Legs to Handprint Thinking: Foundations for Evaluating the Good We Do. *Earths Future* **8**, e2019EF001422 (2020).
34. Katic, P. G., Cerretelli, S., Haggar, J., Santika, T. & Walsh, C. Mainstreaming biodiversity in business decisions: Taking stock of tools and gaps. *Biol. Conserv.* **277**, 109831 (2023).
35. The Ahmedabad Declaration: Applied Environmental Education & Communication: Vol 4 , No 3 - Get Access. *Appl. Environ. Educ. Commun.* https://www.tandfonline.com/doi/full/10.1080/15330150591004698 (2005).
36. White, T. B. *et al.* The "nature-positive" journey for business: A conceptual research agenda to guide contributions to societal biodiversity goals. *One Earth* **7**, 1373–1386 (2024).
37. El Geneidy, S. *et al.* Value-transforming financial, carbon and biodiversity footprint accounting. *ArXiv Prepr. ArXiv230914186* https://doi.org/10.48550/arXiv.2309.14186 (2026) doi:10.48550/arXiv.2309.14186.
38. Ermgassen, S. zu *et al.* The current state, opportunities and challenges for upscaling private investment in biodiversity in Europe. Preprint at https://doi.org/10.31235/osf.io/2u6ky (2024).
39. Maron, M. *et al.* 'Nature positive' must incorporate, not undermine, the mitigation hierarchy. *Nat. Ecol. Evol.* **8**, 14–17 (2024).
40. Arlidge, W. N. S. *et al.* A Global Mitigation Hierarchy for Nature Conservation. *BioScience* **68**, 336–347 (2018).
41. Farrelly, É. *et al.* Towards Nature Positive supply chains: From biodiversity commitments to organisational action. https://ecoevorxiv.org/repository/view/13114/ (2026).

42. Thompson, B. S. Blue bonds for marine conservation and a sustainable ocean economy: Status, trends, and insights from green bonds. *Mar. Policy* **144**, 105219 (2022).
43. Thompson, B. S. Impact investing in biodiversity conservation with bonds: An analysis of financial and environmental risk. *Bus. Strategy Environ.* **32**, 353–368 (2023).
44. Tobin-de la Puente, J. *The Little Book of Nature Business – Global Canopy*. (Global Canopy, 2026).
45. Martin, R. N., Bunje, P. M. & Dehgan, A. O. The extinction solutions index (ESI): A framework to measure solution efficiency to address biodiversity loss. *Ecol. Solut. Evid.* **5**, e12358 (2024).
46. Egli, F., Martin, R., Wildgruber, K., zu Ermgassen, S. & Chapman, M. Mobilising private finance for biodiversity. (2026).
47. White, T. B., Viana, L. R., Campbell, G., Elverum, C. & Bennun, L. A. Using technology to improve the management of development impacts on biodiversity. *Bus. Strategy Environ.* **30**, 3502–3516 (2021).
48. Burek, J. University handprint framework: quantifying the positive impacts of university-led sustainability action research. *Int. J. Sustain. High. Educ.* https://doi.org/10.1108/IJSHE-10-2024-0755 (2025) doi:10.1108/IJSHE-10-2024-0755.
49. Almelhem, M., Buics, L. & Süle, E. Comparison of sustainability and circularity indicators: downstream vs. upstream supply chain strategies. *Discov. Sustain.* **6**, 302 (2025).
50. Sauer, P. C. & Seuring, S. Extending the reach of multi-tier sustainable supply chain management – Insights from mineral supply chains. *Int. J. Prod. Econ.* **217**, 31–43 (2019).
51. Young, S. B. Responsible sourcing of metals: certification approaches for conflict minerals and conflict-free metals. *Int. J. Life Cycle Assess.* **23**, 1429–1447 (2018).
52. Weidema, B. P., Pizzol, M., Schmidt, J. & Thoma, G. Attributional or consequential Life Cycle Assessment: A matter of social responsibility. *J. Clean. Prod.* **174**, 305–314 (2018).

53. Baylis, K. *et al.* Mainstreaming Impact Evaluation in Nature Conservation. *Conserv. Lett.* **9**, 58–64 (2016).

54. Maron, M. *et al.* The many meanings of no net loss in environmental policy. *Nat. Sustain.* **1**, 19–27 (2018).

55. Langhammer, P. F. *et al.* The positive impact of conservation action. *Science* **384**, 453–458 (2024).

56. Martin, R. N., Bunje, P. M. E. & Dehgan, A. O. The Extinction Solutions Index (ESI): A framework to measure solution efficiency to address biodiversity loss. *Ecol. Solut. Evid.* **5**, e12358 (2024).

57. Anthropogenic and Natural Radiative Forcing. in *Climate Change 2013 – The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (ed. IPCC) 659–740 (Cambridge University Press, Cambridge, 2014). doi:10.1017/CBO9781107415324.018.

58. Wauchope, H. S. *et al.* What is a unit of nature? Measurement challenges in the emerging biodiversity credit market. *Proc. R. Soc. B Biol. Sci.* **291**, 20242353 (2024).

59. Kalliolevo, H., Geneidy, S. E. & Kotiaho, J. Global offsetting of the outsourced biodiversity footprint of consumption. https://ecoevorxiv.org/repository/view/10566/ (2025).

60. Brock, K. C. & Bernard, J. The cumulative consequences of multispecies invasions and the great shuffle of biodiversity. *Bioscience* **76**, 45–56 (2025).

61. Miles, N., Duffus, N. E., Bull, J. W. & zu Ermgassen, S. S. O. S. E. An influential biodiversity market may not direct investment toward habitats of national importance. *Conserv. Sci. Pract.* **7**, e70199 (2025).

62. Ramm, K., Brown, C., Arneth, A. & Rounsevell, M. Expansion and increase of human pressures on global land ecosystems between 1990 and 2020. 2026.04.16.718867 Preprint at https://doi.org/10.64898/2026.04.16.718867 (2026).

63. Moilanen, A. & Laitila, J. FORUM: Indirect leakage leads to a failure of avoided loss biodiversity offsetting. *J. Appl. Ecol.* **53**, 106–111 (2016).

64. Norris, G. A., Burek, J., Moore, E. A., Kirchain, R. E. & Gregory, J. Sustainability Health Initiative for NetPositive Enterprise handprint methodological framework. *Int. J. Life Cycle Assess.* **26**, 528–542 (2021).

65. Alvarenga, R. A. F. *et al.* A framework for using the handprint concept in attributional life cycle (sustainability) assessment. *J. Clean. Prod.* **265**, 121743 (2020).

66. Lakanen, L., Kumpulainen, H., Helppi, O., Grönman, K. & Soukka, R. Carbon Handprint Approach for Cities and Regions: A Framework to Reveal and Assess the Potential of Cities in Climate Change Mitigation. *Sustainability* **14**, 6534 (2022).

67. Niero, A., Brenes-Peralta, L., Pölling, B. & Vittuari, M. Exploring social handprints on well-being: a methodological framework to assess the contribution of business models in city region food systems. *Int. J. Life Cycle Assess.* **30**, 1152–1166 (2025).

68. Booth, H., Milner-Gulland, E. J., McCormick, N. & Starkey, M. Operationalizing transformative change for business in the context of Nature Positive. *One Earth* **7**, 1235–1249 (2024).

69. Rizzo, G., Migliore, G., Schifani, G. & Vecchio, R. Key factors influencing farmers' adoption of sustainable innovations: a systematic literature review and research agenda. *Org. Agric.* **14**, 57–84 (2024).

70. Andrew, E. & Pigosso, D. C. A. Multidisciplinary perspectives on rebound effects in sustainability: A systematic review. *J. Clean. Prod.* **470**, 143366 (2024).

71. Figge, F., Young, W. & Barkemeyer, R. Sufficiency or efficiency to achieve lower resource consumption and emissions? The role of the rebound effect. *J. Clean. Prod.* **69**, 216–224 (2014).

72. Taskforce on Nature-related Financial Disclosures (TNFD). *Recommendations of the Taskforce on Nature-Related Financial Disclosures*. https://tnfd.global/publication/recommendations-of-the-taskforce-on-nature-related-financial-disclosures/ (2023).
73. Nature Positive Initiative. Nature Positive Initiative. (2024).
74. Jaureguiberry, P. *et al.* The direct drivers of recent global anthropogenic biodiversity loss. *Sci. Adv.* **8**, eabm9982 (2022).
75. Bull, J. W. *et al.* Towards positive net outcomes for biodiversity, and developing safeguards to accompany headline biodiversity indicators. *Npj Biodivers.* **4**, 31 (2025).
76. Bromwich, T. *et al.* Navigating uncertainty in life cycle assessment-based approaches to biodiversity footprinting. *Methods Ecol. Evol.* https://doi.org/10.1111/2041-210X.70001 (2025) doi:10.1111/2041-210X.70001.
77. Kakar, S. K., Wang, J., Arshed, N., Le Hien, T. T. & Abdullahi, N. M. Investigating the biodiversity conservation capability of technological innovation and FinTech. *Heliyon* **10**, e40683 (2024).
78. Behm, K., Husgafvel, R., Hohenthal, C., Pihkola, H. & Vatanen, S. *Carbon Handprint: Communicating the Good We Do*. (VTT Technical Research Centre of Finland, Espoo, 2016).
79. Pajula, T. *et al. Carbon Handprint Guide V. 2.0 Applicable for Environmental Handprint*. https://lutpub.lut.fi/handle/10024/162537 (2021).
80. Nurdiawati, A., Mir, B. A. & Al-Ghamdi, S. G. Recent advancements in prospective life cycle assessment: Current practices, trends, and implications for future research. *Resour. Environ. Sustain.* **20**, 100203 (2025).
81. Marson, A., Benozzi, A. & Manzardo, A. Looking to the Future: Prospective Life Cycle Assessment of Emerging Technologies. *Chem. – Eur. J.* **31**, e202500304 (2025).
82. Zu Ermgassen, S. O. S. E. *et al.* Five rules for scientifically credible nature markets. *Nat. Ecol. Evol.* **10**, 181–192 (2026).

83. Jalkanen, J. *et al.* Defining ecologically realistic biodiversity offset multipliers with the Response-based Habitat Hectare Assessment of Biodiversity Gains (REHAB). 2026.01.26.701764 Preprint at https://doi.org/10.64898/2026.01.26.701764 (2026).
84. Kasurinen, H. *et al.* Carbon Handprint: Potential Climate Benefits of a Novel Liquid-Cooled Base Station with Waste Heat Reuse. *Energies* **12**, 4452 (2019).
85. Balmford, A. *et al.* Time to fix the biodiversity leak. *Science* **387**, 720–722 (2025).
86. Crenna, E., Marques, A., La Notte, A. & Sala, S. Biodiversity Assessment of Value Chains: State of the Art and Emerging Challenges. *Environ. Sci. Technol.* **54**, 9715–9728 (2020).
87. European Commission. Align bears fruit in shaping the future of biodiversity measurement approaching its final stretch - European Commission. https://green-business.ec.europa.eu/news/align-bears-fruit-shaping-future-biodiversity-measurement-approaching-its-final-stretch-2023-12-06_en (2023).
88. Marques, A., Verones, F., Kok, M. T., Huijbregts, M. A. & Pereira, H. M. How to quantify biodiversity footprints of consumption? A review of multi-regional input–output analysis and life cycle assessment. *Curr. Opin. Environ. Sustain.* **29**, 75–81 (2017).
89. Wilting, H. C., Schipper, A. M., Bakkenes, M., Meijer, J. R. & Huijbregts, M. A. J. Quantifying Biodiversity Losses Due to Human Consumption: A Global-Scale Footprint Analysis. *Env. Sci Technol* **51**, 3298 (2017).
90. Duelli, P. & Obrist, M. K. Biodiversity indicators: the choice of values and measures. *Agric. Ecosyst. Environ.* **98**, 87–98 (2003).
91. Magurran, A. E. Measuring biological diversity. *Curr. Biol.* **31**, R1174–R1177 (2021).
92. Haberl, H. *et al.* A systematic review of the evidence on decoupling of GDP, resource use and GHG emissions, part II: synthesizing the insights. *Environ. Res. Lett.* **15**, 065003 (2020).
93. Bärnthaler, R. & Gough, I. Provisioning for sufficiency: envisaging production corridors. *Sustain. Sci. Pract. Policy* **19**, 2218690 (2023).

94. Santos, C., Coelho, A. & Marques, A. A systematic literature review on greenwashing and its relationship to stakeholders: state of art and future research agenda. *Manag. Rev. Q.* **74**, 1397–1421 (2024).

95. White, T. B. *et al.* Principles for using evidence to improve biodiversity impact mitigation by business. *Bus. Strategy Environ.* **32**, 4719–4733 (2023).

96. Godfray, H. C. J., Poore, J. & Ritchie, H. Opportunities to produce food from substantially less land. *BMC Biol.* **22**, 138 (2024).

97. Frig, M., Jaakkola, M. & Olkkonen, L. The dual climate impact of news media: The carbon footprint-handprint challenges in Nordic commercial news media organizations. *MedieKultur J. Media Commun. Res.* **41**, (2025).

98. Narain, D. *et al.* A framework for capturing indirect impacts in site-level screening for biodiversity risks. *Methods Ecol. Evol.* **n/a**, (2025).