

1 Towards Nature Positive supply chains: From biodiversity
2 commitments to organisational action

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21 Abstract

22 Large organisations are critical to halting and reversing biodiversity loss, and increasingly
23 making bold commitments for nature. However, translating commitments into action requires
24 robust strategies to fully identify, quantify, trace, and act. This is particularly pertinent because
25 most organisational impacts are hidden within complex supply chains. Here we present a novel,
26 generalised, and scalable approach to assessing and addressing supply chain impacts on
27 biodiversity, demonstrating its applicability using a large organisation (Oxford University). We
28 show how organisations can evaluate supply chain traceability and transparency, estimate
29 region-specific biodiversity impacts, and harness collaborations for impact mitigation. Among
30 Oxford's 131 highest-spend suppliers, only 18 disclosed raw material origins, with two offering
31 product life-cycle assessments, evidencing the major traceability gap resulting in a systemic
32 accountability barrier. We home in on a single product (coffee) to demonstrate how
33 organisations could move beyond diagnosis to action: Applying life cycle impact assessment
34 to estimate Oxford's coffee procurement biodiversity footprint and demonstrate translation of
35 these insights into practical, collaborative interventions with in-country partners. By shifting
36 the focus beyond diagnosing supply chains as a major driver of biodiversity loss to delivering
37 actionable solutions, this study provides a scalable pathway for large organisations to
38 contribute to global nature recovery.

39

40 Main

41 Organisations are increasingly articulating commitments to action on nature and exploring
42 approaches to measure their biodiversity impacts and dependencies, in response to policy
43 expectations and growing awareness of the social and economic risks of nature loss¹⁻⁵. Yet
44 despite this momentum and the critical role organisations must play, there remains little clarity
45 on how they can translate ambition into credible, applicable steps for the majority of their
46 biodiversity footprint, which often lies upstream in complex and opaque supply chains⁶⁻¹¹.
47 Here, we demonstrate a practical and defensible pathway for organisations to reduce harm,
48 generate positive outcomes, and contribute to systemic change, towards a Nature Positive
49 future¹².

50 Supply chains typically have low traceability (i.e., ability to determine product origins) and
51 transparency (i.e., disclosure of product information), making it difficult to link procured
52 products to on-the-ground biodiversity impacts and accurately quantify associated losses¹³⁻¹⁵.
53 This hinders information flow along value chains and limits the design of effective mitigation
54 strategies, including appropriate prioritisation and justification of interventions^{16,17}. While
55 platforms such as Trase and Open SC improve traceability by mapping global commodity
56 flows, they are limited by a focus on agricultural commodities and their operation at national
57 or regional scales¹⁸⁻²⁰. Bottom-up mitigation approaches developed by and for individual
58 organisations and their supplier networks to address supply chain impacts remain rare yet are
59 essential for delivering meaningful and measurable outcomes.

60 Existing guidelines for addressing organisational impacts prioritise the prevention of impacts
61 (i.e., avoidance and reduction) ahead of compensatory actions (i.e. restoration and offsetting)
62 in line with the Mitigation Hierarchy²¹. The Science-Based Targets for Nature (SBTN)
63 emphasise this by explicitly excluding compensatory actions and offsets within the Land

64 standard, currently the most developed SBTN domain²². In practice, this prioritisation requires
65 organisations to interrogate what is considered “mission-critical” and to pursue avoidance and
66 reduction strategies wherever possible. This may include actions such as zero-deforestation
67 commitments in supply chains, sourcing certified produce with lower biodiversity impacts,
68 reducing waste, reducing overall material consumption, and promoting circular use of materials
69 (e.g. mandating refurbished IT and furniture), for which environmental benefits have been
70 demonstrated in the case of laptops²³⁻²⁶. Nonetheless, even under ambitious avoidance and
71 reduction strategies, certain products are likely to continue exerting unavoidable pressures on
72 biodiversity²⁷. Consistent with this, the biodiversity footprint assessment of the University of
73 Oxford shows that even under a high-avoidance scenario, one third of the business-as-usual
74 biodiversity footprint remains as residual impact requiring compensatory action⁷.

75 As organisations set more ambitious Nature Positive commitments, there is therefore a growing
76 need for guidance to ensure that compensatory actions for unavoidable and residual supply
77 chain impacts are credible, transparent, and deliver lasting biodiversity gains, as equivalent as
78 possible to the original negative impacts²⁸. While actions to avoid and minimise impacts are
79 well defined (e.g. through SBTN), far less clarity exists on how organisations should implement
80 positive actions to compensate for biodiversity impacts when uncertainties are high, and losses
81 and gains are difficult to match²⁹.

82 A key source of uncertainty lies in the methods commonly used to quantify and compare
83 biodiversity impacts across supply chains. Generic life cycle assessments (LCA) are a widely
84 applied method, used by organisations to assess and compare the relative biodiversity impacts
85 of different activity streams, enabling prioritisation of impact categories that require more
86 detailed investigation³⁰⁻³³. However, these approaches are often not spatially explicit and have
87 numerous sources of uncertainty. For example, outputs are typically averaged across large

88 regions. This limits the usefulness of LCA outputs to justify actions, and for the design of
89 distinct, spatially explicit mitigation and conservation actions that can compensate for impact.

90 Here, by contrast, we take a bottom-up approach to examine the biodiversity impacts of an
91 organisation's supply chains and identify how these impacts can be addressed through targeted,
92 actionable mitigation and conservation. We build on Bull et al. (2022), which demonstrated
93 that most of the University of Oxford's biodiversity footprint arises from its supply chains, but
94 left unresolved how such impacts might be traced to a finer spatial scale and mitigated in ways
95 that contribute to a Nature Positive future. We structure the analysis using the Mitigation and
96 Conservation Hierarchy (MCH), which provides a framework for addressing dispersed impacts
97 across complex supply chains, not only helping to prevent inaction where residual impacts
98 cannot be directly offset, but also supporting systemic and transformational change towards
99 Nature Positive outcomes^{34,35}.

100 After assessing the traceability and transparency of the University of Oxford's major supply
101 chains, we focus on coffee as a single case study product to demonstrate approaches for
102 estimating the biodiversity footprint of a key raw commodity at source. We then evaluate
103 mitigation and conservation opportunities to address these impacts with in-country
104 collaborators. This analysis informs the development of a generalised workflow applicable to
105 other products procured by the University of Oxford, and to other organisations more broadly
106 (Fig.1).

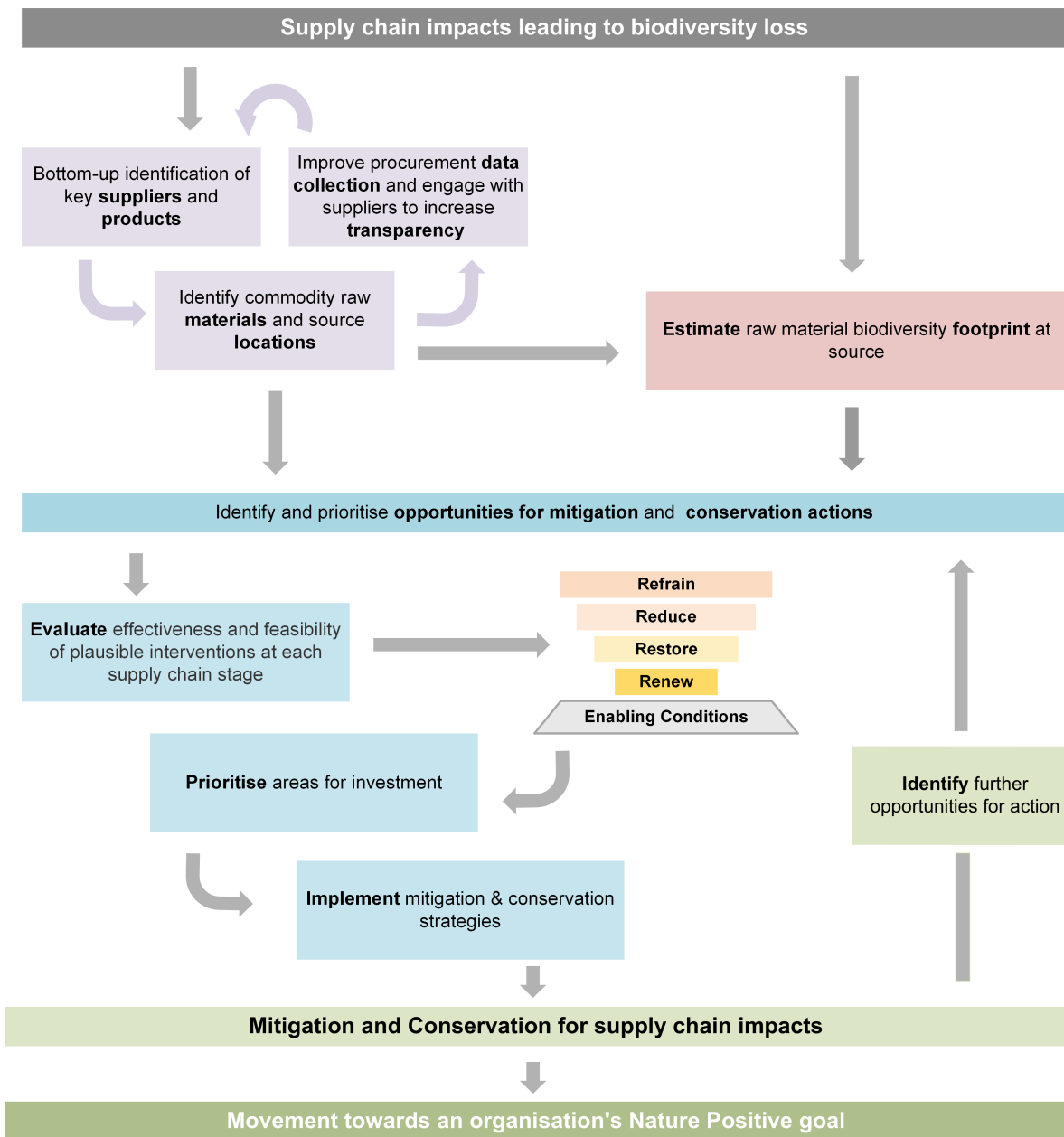
107 We do not assume numerical equivalence between upstream, life-cycle-based supply chain
108 impacts and actual impacts, as this risks oversimplifying ecological complexity, and is widely
109 recognised as practically unfeasible^{31,36}. Decision-making frameworks that rely on averaged or
110 model-derived impacts are inherently constrained in their ability to guide credible
111 compensatory action, as they detach impacts away from the actors, locations and decisions

112 required to address them. In response, we use the MCH to identify feasible, evidence-based
113 interventions across the supply chain and demonstrate how organisations can progress from
114 impact measurement to prioritised action. Although more analytically demanding than
115 approaches based on averages, this workflow increases ecological and spatial alignment
116 between supply chain impacts and mitigation and conservation actions by grounding decisions
117 in actual sourcing relationships. This subsequently enables more proportionate, transparent,
118 and on-the-ground responses to biodiversity loss.

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121 Fig. 1: Generalised Workflow



122
 123 Figure 1: Generalised workflow for addressing biodiversity impacts in organisational supply
 124 chains, in support of Nature Positive goals. The workflow links supply chain traceability and
 125 transparency with mitigation and conservation action through the Mitigation and Conservation
 126 Hierarchy (MCH). Colours denote the main analytical components, with traceability and raw
 127 material mapping shown in parallel to reflect that these processes can occur simultaneously.
 128 Purple arrows indicate how increased supplier engagement and data transparency can improve
 129 understanding of raw material origins, enabling targeted interventions to reduce upstream
 130 biodiversity pressures. The inverted pyramid illustrates the MCH stages (Refrain, Reduce,
 131 Restore, Renew), supported by enabling conditions that facilitate action but do not directly
 132 generate biodiversity benefits. Applied to the University of Oxford's supply chains, the
 133 workflow highlights how existing collaborations can support the identification and
 134 implementation of mitigation and conservation opportunities.

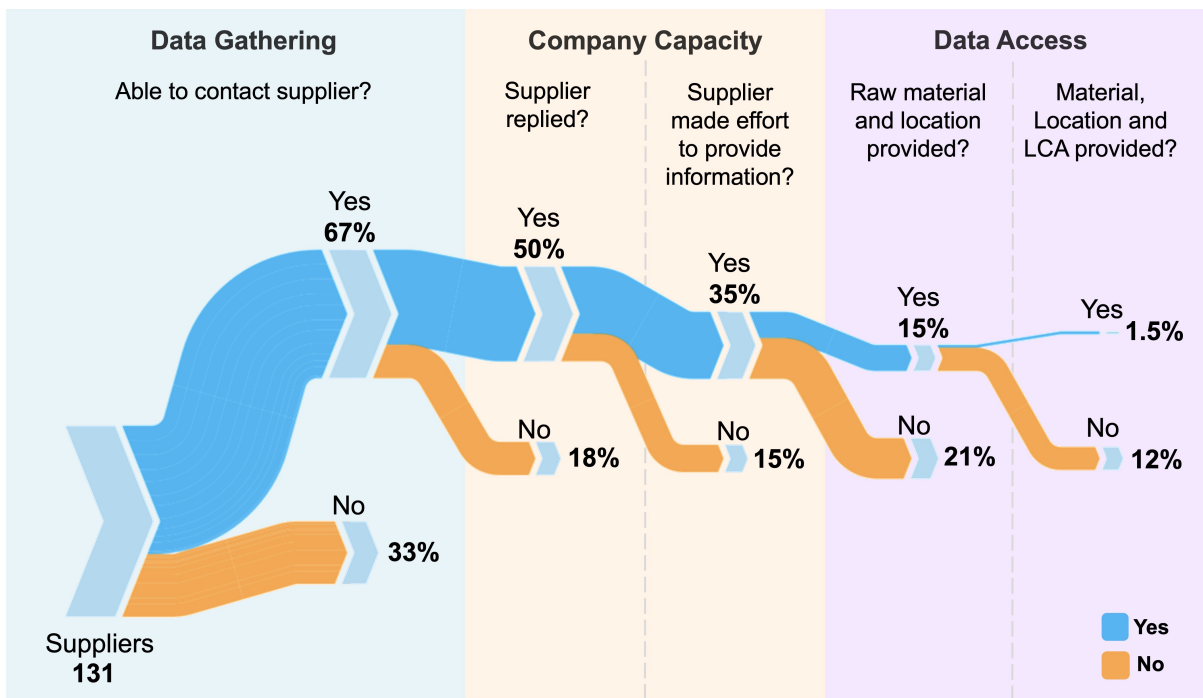
135 Assessing traceability and transparency

136 We assessed traceability and transparency across the University of Oxford's research,
137 operations, and construction supply chains, corresponding to the first stage of our workflow
138 (Fig. 1; see Methods and Supplementary Information S1 for details). This analysis aimed to
139 determine the origin and composition of the University's highest-expenditure products,
140 identifying where procurement activities may exert pressure on biodiversity globally.

141 The results revealed a pronounced traceability gap, reflecting a fundamental challenge that
142 organisations face in addressing biodiversity impacts (Fig. 2; Supplementary Information
143 S1.8). Despite substantial efforts to contact all 131 highest-expenditure suppliers, this was
144 possible for only 67% (88 suppliers) due to incomplete invoice records or missing contact
145 information, and only half of those contacted responded. Eighteen suppliers identified product
146 origins or raw materials for at least one item that they supply to the university, but only two
147 suppliers (<2%) shared complete information for at least one item, including sourcing
148 locations, raw materials, and LCA data. Both of these items belonged to the "Office,
149 Classroom, Library and Outdoor Furniture" subcategory within the operations supply chain.
150 This sharp decline of data availability and supplier engagement at each stage of data collection
151 indicates a progressive loss of traceability and transparency from initial contact through to final
152 acquisition of raw material and life cycle data (Fig. 2). The extensive organisational effort and
153 repeated outreach required to obtain even partial data from suppliers highlights the substantial
154 resource burden of this process, which itself constitutes a major constraint on achieving full
155 supply chain transparency and traceability.

156

157 Fig. 2: Traceability and Transparency along the Supply Chain



158
 159 Figure 2: Decline in supply chain traceability and transparency across the University of
 160 Oxford’s procurement categories. Sankey diagram illustrates the progressive loss of
 161 traceability and transparency across research, operations and construction supply chains,
 162 structured into three stages: “Data Gathering” (ability of researchers to contact suppliers),
 163 “Company Capacity” (supplier response and willingness to provide information), and “Data
 164 Access” (provision of raw material, location, and life cycle data). Blue and orange flows
 165 indicate “yes” and “no” responses, respectively, at each stage.

166 The structure of supply chains combines vertical complexity (multiple tiers of suppliers) with
 167 horizontal complexity (diverse raw materials sourced across regions)^{37,38}. Within the
 168 University of Oxford’s procurement network, 42 suppliers (48%) acted as distributors rather
 169 than manufacturers (i.e. companies that sell products made by others), increasing vertical
 170 complexity by adding distance from production sources³⁹. Only 15 distributors were willing to
 171 contact upstream suppliers, indicating limited transparency beyond first-tier relationships.
 172 Increased provision of data was therefore concentrated among suppliers operating in simpler
 173 product categories, with the two suppliers providing complete data belonging to a furniture
 174 subcategory characterised by fewer components and more localised sourcing.

175 Confidentiality was the most frequently reported barrier to information disclosure, where
176 nearly half of suppliers (48%) declined or were unable to share data on raw material
177 composition, and 43% did not provide sourcing locations. Only five suppliers collected or
178 shared LCA data, and this was limited to carbon footprints. Together, these results indicate the
179 systemic opacity of organisational supply chains, driven by limited traceability, weak upstream
180 engagement, confidentiality barriers, and the absence of governance structures providing clear
181 expectations for transparency^{40,41,15}. Addressing these constraints will require both stronger
182 supplier engagement and standardised data collection protocols, which record not only
183 financial expenditure but also product weight and quantity. In addition, material composition
184 and sourcing geography should be captured, and underpinned by governance mechanisms and
185 legal requirements that create clearer expectations for disclosure and accountability. Such
186 information is essential for more granular estimation of biodiversity impacts and for the design
187 of targeted interventions towards Nature Positive outcomes.

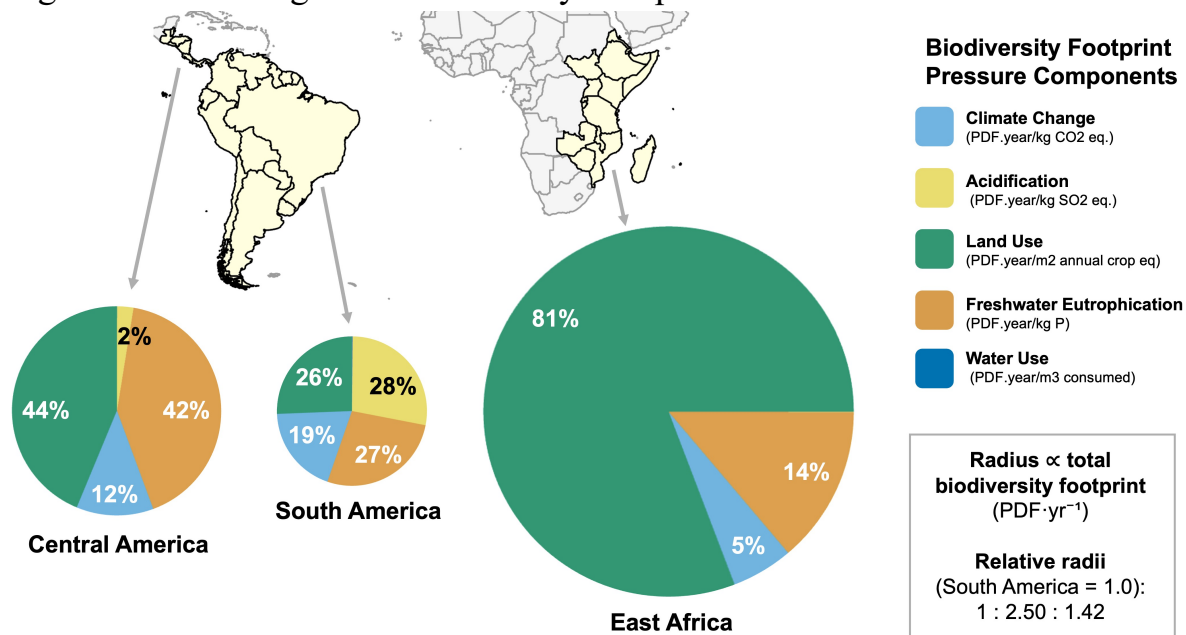
188 To demonstrate how improved data availability can inform action, we chose a single
189 commodity - coffee - for deeper investigation. We selected coffee as it is a raw (rather than
190 composite) product with high biodiversity impact, high socioeconomic importance, and is
191 partially traceable to the country-level within the Oxford purchasing system⁴²⁻⁴⁵. This enabled
192 us to demonstrate how knowledge of sourcing regions can be used to estimate biodiversity
193 impacts using established life cycle impact assessment (LCIA) methods^{7,30}.

194 Estimating coffee's biodiversity footprint

195 For the 2022-23 financial year, the University of Oxford's coffee purchases were associated
196 with a total estimated biodiversity footprint of 2.68×10^{-9} PDF·year, aggregated across the
197 three sourcing regions (the "potentially disappeared fraction" of species, estimated to be lost
198 over one year due to environmental impacts such as land use, climate change etc., quantified

199 using LCIA approaches; see Methods)⁴⁶. The three University of Oxford coffee sourcing
200 regions had marked differences in both the estimated magnitude and composition of
201 environmental impact pathways (Fig. 3). Coffee sourced from East Africa had the largest
202 estimated biodiversity footprint (1.81×10^{-9} PDF.year), around three times higher than if
203 sourced from Central America and six times higher than South America. This difference was
204 driven primarily by the greater land use requirements per kilogram in the LCA data used to
205 estimate impacts of coffee grown in East Africa, making land use the dominant environmental
206 pressure in the region (81%)⁴⁷. In Central America, land use was also the largest contributor
207 (44%), but eutrophication and climate change impacts played proportionally larger roles. In
208 contrast, South America exhibited a distinct profile, with acidification contributing the largest
209 share (28%), and land use being relatively smaller. Across all regions, water use contributed
210 negligibly to overall endpoint biodiversity impacts.

211 Fig. 3: Coffee's Regional Biodiversity Footprint



212
213

214 Figure 3: Composition and magnitude of the biodiversity footprint of coffee across sourcing
 215 regions. Pie charts show the proportional contributions of five environmental pressures
 216 (climate change, acidification, land use, freshwater eutrophication, and water use) to the
 217 estimated biodiversity footprint of coffee sourced from Central America, South America, and
 218 East Africa. Pie chart radii are scaled to the total biodiversity footprint of each region.
 219

220 These patterns are consistent with previous work showing that sourcing location strongly
 221 influences both the magnitude and nature of biodiversity pressures, including for coffee, where
 222 impacts such as carbon footprint and water scarcity vary substantially by origin^{48,49}. However,
 223 LCIA-based biodiversity footprint estimates carry inherent uncertainties due to variation in
 224 model assumptions, data quality, coarse spatial resolution, and category aggregation (see
 225 Supplementary Information S2.3 for a sensitivity test comparing estimates across different
 226 LCIA models)^{31,50}. As such, the values reported here are indicative of relative pressures across
 227 sourcing regions rather than precise absolute impacts. Nonetheless, they offer a transparent
 228 basis for comparing relative impacts and assessing the potential mitigation benefits of different
 229 actions.

230 Opportunities for targeted mitigation and conservation

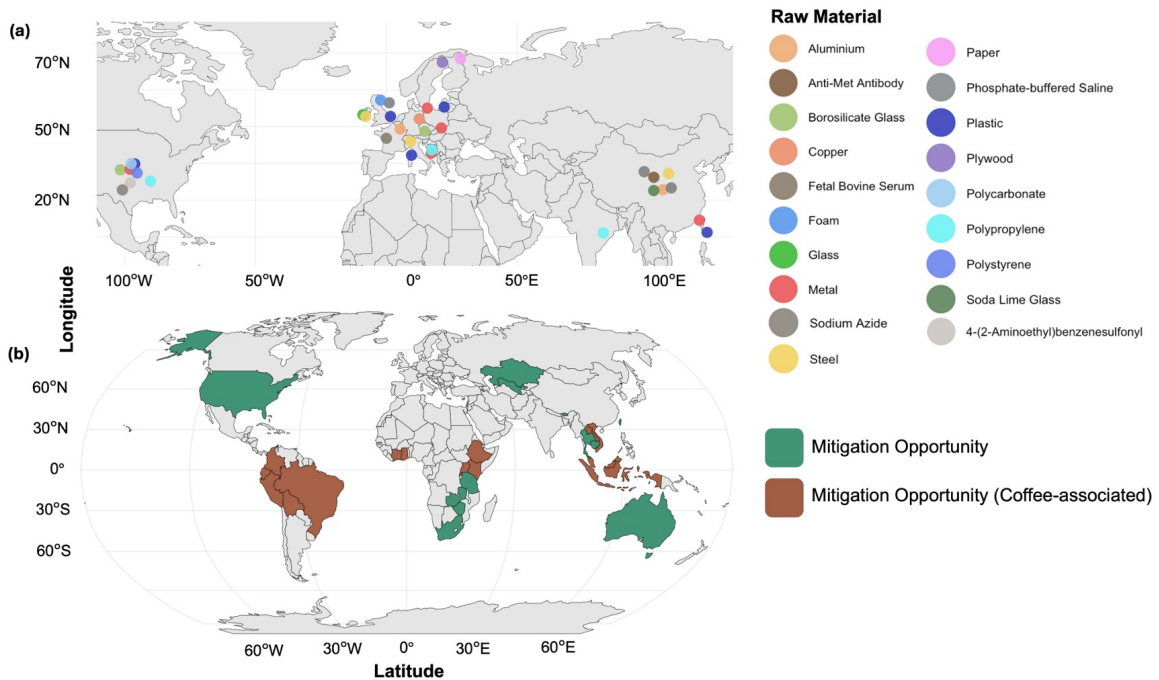
231 Regional variation in biodiversity pressures arising from supply chain activities emphasises the
232 need for locally tailored mitigation and conservation approaches^{48,51}. Accordingly,
233 organisations seeking to address biodiversity impacts should identify collaborators in sourcing
234 areas, who can recognise, implement, monitor, and report on locally relevant mitigation
235 actions. These collaboration opportunities will differ between organisations, but could include
236 suppliers, NGOs, researchers, and/or other landowners. We demonstrated how this could be
237 done for a university by reaching out to researchers based at the University of Oxford working
238 both generally on biodiversity and specifically on coffee, to answer a survey about their
239 research collaborations. Researchers were identified through initial contacts and snowball
240 sampling, with respondents asked to highlight other researchers working on coffee- and
241 biodiversity-relevant collaborations. As this was a demonstrative exercise, we did not aim to
242 map all collaborations; however, no additional coffee-related projects emerged during the
243 survey, suggesting saturation within the defined scope.

244 To contextualise these collaboration opportunities, we first mapped the global distribution of
245 the University of Oxford's raw material suppliers (from the 18 suppliers who provided at least
246 one raw material and source location; Fig. 2; Fig. 4a). We then compared these sourcing
247 locations with reported research collaborations that could support biodiversity mitigation and
248 conservation (Fig. 4b).

249 The 34 biodiversity and conservation researchers responding to our survey reported 69
250 collaborations across all inhabited continents. Of these, 47 (68%) indicated they could support
251 supply chain impact mitigation or conservation strategies, including 23 (49%) that either
252 directly involved coffee-related projects or were located within coffee-sourcing regions.

253

254 Fig. 4: Global maps of Oxford supplier raw material locations and research
 255 collaborations



256
 257 Figure 4: (a) Global distribution of the University of Oxford’s raw material suppliers (food
 258 supply chain excluded; see Supplementary Information S1.4). Coloured points indicate source
 259 locations for materials used across research, operations, and construction supply chains. Points
 260 are not scaled by quantity or volume due to incomplete data, and displaced centroids are used
 261 to separate overlapping country locations. (b) Countries in which University of Oxford
 262 researchers have reported collaborations with potential to support conservation and mitigate
 263 biodiversity impacts in the University’s supply chains. Green shading indicates general
 264 mitigation opportunities, while brown shading denotes coffee-associated opportunities, either
 265 through research explicitly focused on coffee or located within coffee-growing areas.

266

267 In this particular study, we illustrate Oxford’s sourcing locations more generally (Fig. 4a) and
 268 then focus on identifying opportunities for mitigation and conservation for coffee only, as this
 269 is the focus of our case study (Fig. 4b). As sourcing information improves, these hotspots could
 270 be cross-referenced with locations of active research collaborations to identify existing
 271 overlaps, or, where appropriate, guide procurement towards regions where strong research ties
 272 already exist. Such alignment could facilitate the co-development of locally informed
 273 mitigation and conservation strategies, supported by transparent financial flows and monitored

274 through ongoing in-country partnerships (see Supplementary Information S4.1, Fig. S8, for
275 examples of actions and strategies for mitigation of coffee supply chain impacts, aligned with
276 the MCH). Footprint results could also inform longer-term procurement strategies, including
277 shifts away from regions associated with particularly high biodiversity impacts.

278 Other universities accounted for a large share of both the University of Oxford's general and
279 coffee-specific collaboration opportunities (30 general, 18 coffee-related), while NGOs played
280 a substantial but less coffee-focused role (33 and 13 respectively). Most collaborations were
281 research-oriented (36 general and 17 coffee-related), followed by implementation-focused (22
282 and 9, respectively). Researchers noted that mitigation-relevant collaborations commonly
283 involved community-based conservation or links with specific farms where interventions could
284 be implemented (Supplementary Information S3.4 Table S18). Beyond direct footprint
285 reduction, such collaborations may also generate indirect positive outcomes for biodiversity,
286 often referred to as "handprints"⁵². For example, research and monitoring activities could
287 contribute improved knowledge of how to design effective mitigation and conservation actions,
288 which could then be used by others. Additionally, such collaborations could be structured as
289 equitable and inclusive partnerships providing mutual benefits (e.g. joint educational
290 opportunities).

291 Guided by the wider literature, we identified four stages of the coffee supply chain - cultivation,
292 processing, retail, and consumption - and mapped opportunities for targeted interventions at
293 each stage, linking them to the MCH (Supplementary Information S4.1 Fig. S8)^{53,54}. Pressure
294 profiles differed across early stages. While land use was primarily associated with cultivation,
295 water consumption was more closely linked to processing due to wet milling and washing
296 activities^{55,56}. Freshwater eutrophication and climate change pressures were evident across both
297 stages. This differentiation helps identify where efforts might be most effective. For example,
298 East Africa's large land use component (Fig. 3) indicates that cultivation-focused interventions

299 may yield substantial benefits. More broadly, these results suggest that action prioritisation
300 depends on a combination of supply chain stage, regional pressure composition, and position
301 within the MCH. Midpoint LCIA profiles can therefore inform the targeting of interventions
302 across supply chain stages, geographies and MCH steps, while recognising inherent
303 methodological uncertainties^{22,31}.

304 Scenario Analysis: A Sustainable Coffee Transition in Kenya

305 To demonstrate how the generalised workflow (Fig. 1) can be operationalised, we developed
306 an illustrative scenario using a sourcing region (East Africa) paired with an existing research
307 collaboration for coffee (Supplementary Information S4.3 Fig. S10). Although neighbouring
308 Burundi was the East African sourcing location identified from limited supplier data, Kenya
309 was selected because it hosts the largest cluster of Oxford's biodiversity and conservation
310 partnerships and has midpoint characterisation factors available for most relevant pressures⁴⁷.
311 Kenya also offers a more tractable context for intervention design: all coffee growers must be
312 formally registered, with smallholders predominantly organised through cooperatives,
313 facilitating traceability and coordinated mitigation^{57,58}. In addition, Kenya is strengthening
314 national traceability systems to comply with the European Union's Deforestation Regulation
315 (EUDR) and is among the few African producer countries with a coordinated compliance
316 framework linking regulators, cooperatives, and exporters, further increasing the feasibility for
317 supply chain mitigation and conservation action⁵⁹.

318 The illustrative scenario maintained the University of Oxford's annual procurement volume
319 (3,468 kg yr⁻¹) but recalculated the associated biodiversity footprint under a hypothetical
320 sourcing assumption where all coffee was sourced from Kenya. Under this sourcing
321 assumption, the recalculated biodiversity footprint was 4.14×10^{-9} PDF·year, driven

322 predominantly by land use pressures (81%), followed by eutrophication (14%) and greenhouse-
323 gas emissions (5%), with negligible contributions from acidification and water use.

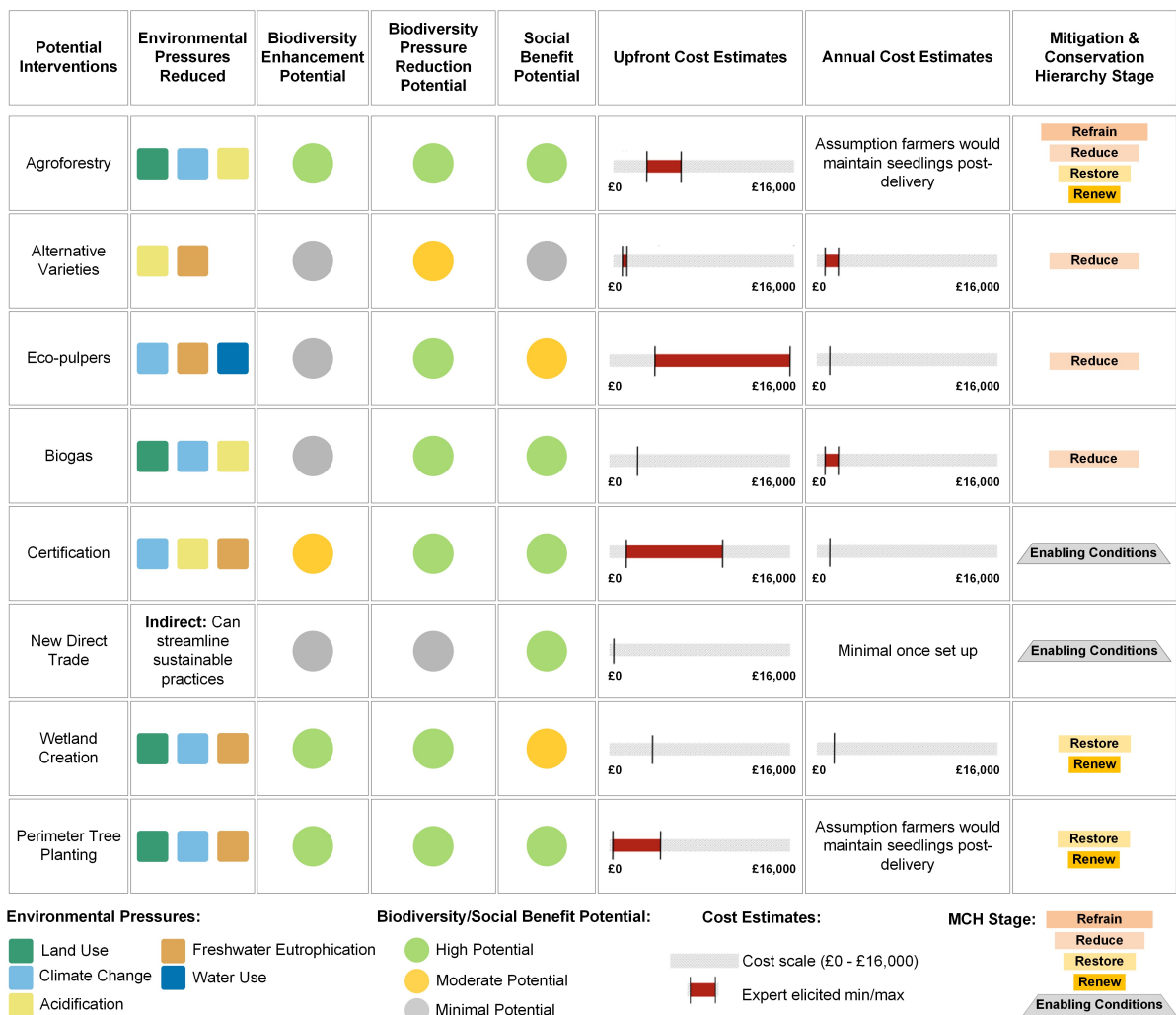
324 Oxford- and Kenya-based researchers co-developed impact mitigation options, first, drawing
325 on academic and grey literature to identify promising approaches, informed by in-country
326 knowledge of coffee production processes, cultural context, and implementation realities.
327 Through repeated rounds of discussion, we proposed, refined, and assessed potential mitigation
328 actions, converging on an intervention list that was evidence-informed and feasible within the
329 local context. We prioritised mitigation actions capable of addressing multiple pressures while
330 also delivering biodiversity, social, and research partnership co-benefits. This was in line with
331 the University's Environmental Sustainable Strategy, with its mission of developing global,
332 equitable partnerships and ambition to contribute to a nature positive societal goal⁶⁰.

333 The process highlighted the need for mitigation pathways tailored to both buyer and sourcing
334 context. Key considerations included the level of buyer commitment, budget constraints, and
335 feasibility of implementation, informed by multiple criteria including effectiveness, costs,
336 stakeholder acceptability, and technical or practical considerations. Options for ongoing
337 monitoring were also important for the decision-making process (Supplementary Information
338 S4.2 Fig. S9). Robust monitoring is essential to determine whether planned interventions
339 deliver intended biodiversity outcomes and to document evidence of their effectiveness over
340 time, particularly where impacts occur in landscapes distant from the actor, such as in complex
341 and spatially heterogeneous supply chains⁶¹.

342 Across the interventions assessed, agroforestry showed the strongest combined potential for
343 pressure reduction, biodiversity enhancement and social benefit⁶²⁻⁶⁵. Agroforestry also fell
344 toward the lower end of expert-elicited cost ranges, both upfront and annually, and was
345 applicable across all stages of the MCH (Fig. 5). Perimeter tree planting and wetland creation

346 also offered large potential impact mitigation benefits, though aligned with the later MCH
 347 stages (“restore” and “renew”), and so would follow - or supplement - actions at earlier stages
 348 of the hierarchy. Other interventions offered more specific benefits: alternative coffee varieties
 349 reduced disease risk, which is increasing under climate change, while eco-pulpers and biogas
 350 systems improved water and energy efficiency⁶⁶⁻⁶⁸. Certification and direct trade arrangements
 351 acted primarily as enabling conditions, strengthening training, governance, and market stability
 352 rather than directly reducing pressures^{69,70}.

353 Fig. 5: Potential interventions in Kenyan coffee supply chains



354 Figure 5: Traffic-light circles denote the estimated potential - high (green), moderate (orange),
 355 or minimal (grey) - for biodiversity enhancement, biodiversity pressure reduction and social or
 356 farmer benefits, based on scoring of scalability, directness, and feasibility. Cost ranges show
 357 expert-elicited minimum and maximum upfront or annual expenses, reflecting typical project
 358

359 experience and are intended as indicative rather than exhaustive. Combined interventions may
360 generate synergistic benefits. Mitigation and Conservation Hierarchy stages follow standard
361 definitions, and enabling conditions denote supporting actions rather than direct biodiversity
362 measures.

363

364 Cost estimates often carry substantial uncertainty, and environmental project budgets are
365 frequently characterised by systematic underestimation^{71,72}. To contextualise intervention
366 rankings, we therefore present expert-elicited cost ranges, noting that approximate values can
367 still support conservation planning when transparently reported and interpreted within bounded
368 scenarios (Fig. 5)⁷³.

369 Final Scenario Design

370 To illustrate how our findings could inform procurement decisions at a granular level, we
371 developed a single scenario to represent a potential on-the-ground implementation of supply
372 chain mitigation action for coffee. We chose Mount Elgon, Kenya, as a hypothetical
373 smallholder production region due to its potential for collaborative engagement, through
374 longstanding research partnerships with Oxford⁵⁷. Drawing on the Kenya-based co-authors'
375 in-country research experience and collective knowledge of regional coffee supply chains, we
376 estimated that supplying approximately 3,400 kg yr⁻¹ would involve around 20–50
377 smallholders, typically operating within cooperative structures, and as Oxford's current supply
378 is Rainforest Alliance (RFA) certified, the scenario assumes this certification as a baseline.

379 The resulting scenario combines three complementary, low to medium-cost interventions
380 selected for their pressure-reduction potential, biodiversity benefits, social outcomes and cost-
381 effectiveness within the sourcing and organisational constraints outlined above. Based on the
382 ranking results, agroforestry was selected as the core measure because it demonstrated the
383 strongest combined ecological and social performance, directly addressed land use impacts,

384 and can provide visible, trackable progress through the establishment and growth of newly
385 planted trees (Fig. 5).

386 While not all shade-grown coffee systems inherently support biodiversity, a substantial body
387 of evidence indicates that agroforestry practices incorporating native tree species can enhance
388 habitat complexity, support a wide range of taxa, and promote resilience to the effects of climate
389 change^{74-77, 62}. Such systems have been shown to maintain or increase coffee yields.

390 However, biodiversity and production outcomes of agroforestry are mediated by management
391 intensity and structural complexity. Intensified systems characterised by simplified canopies
392 and higher agrochemical inputs are consistently associated with biodiversity loss, whereas low-
393 intensity, structurally complex agroforestry systems enhance biodiversity, ecosystem service
394 provision, and coffee plant health⁷⁸⁻⁸⁰. To mitigate the risk of yield reductions translating into
395 unintended land use expansion, and to realise the biodiversity benefits of coffee agroforestry,
396 such systems should be accompanied by yield monitoring and organisational-level demand
397 moderation.

398 Strengthening certification practices could be a pragmatic supplementary intervention, building
399 on Oxford's existing baseline of purchasing Rainforest Alliance (RFA) certified coffee.
400 Certification is a widely used enabling mechanism for coffee, with potential to support
401 improved agrochemical and water management, strengthen cooperative governance and
402 provide structured systems for farmer training and transparent monitoring of certification-
403 linked income premiums⁶⁹. Certification also complements agroforestry systems, as increased
404 shade cover can help meet criteria used in "bird-friendly" certification schemes⁸¹.

405 However, certification has not consistently delivered biodiversity or production gains,
406 highlighting the importance of strengthening scheme design and implementation to better
407 deliver durable ecological and livelihood outcomes⁶⁹. In particular, higher rates of uptake

408 among higher-income households suggest a need to pair certification with targeted support
409 mechanisms that improve accessibility and equity, potentially delivered through these
410 intervention projects implemented with in-country partners. Alternatives to conventional
411 certification therefore also present an avenue for further investigation. Participatory Guarantee
412 Systems, for example, provide community-led verification and low-cost assurance, and may
413 address well-documented limitations of standard third-party certification schemes. Exploring
414 such systems also creates opportunities for collaborative research on their social and ecological
415 outcomes, to support more sustainable and transparent supply chains⁸².

416 The facilitation of direct-trade relationships was selected as a further option for low-cost action
417 to improve price stability and market access for cooperatives, thereby supporting farmer
418 income security and strengthening the conditions required for sustained ecological practice⁵⁴.
419 Direct trade relationships could also bring in a wider network (e.g. of other coffee-purchasing
420 universities), thereby supporting systemic change within the sector.

421 Together, these measures formed the most effective set within the expert-elicited cost range
422 (£4.90k-16.4k for combined up-front costs, and £0.76k-1.90k for combined annual costs),
423 allowing for wider farmer engagement and earlier observable outcomes than higher-cost
424 technological alternatives. We did not attempt to calculate the potential biodiversity gain from
425 this scenario and compare it directly to the estimated biodiversity impact of Oxford's coffee
426 purchases, as this would be comparing two highly uncertain incommensurate measures, neither
427 of which has a robust evidence base. However, by concentrating supply of this product into a
428 specific location and engaging with partners on the ground to implement and monitor the
429 biodiversity impacts, this scenario would enable such analyses to be carried out in future.

430 These proposed mitigation actions are not supposed to be exhaustive; indeed, additional
431 measures - such as perimeter tree planting, wetland restoration, eco-pulpers or biogas systems

432 - were also identified as potential mitigation options (see Supplementary S4.4). These actions
433 would typically require greater upfront investment, higher levels of coordination, or additional
434 infrastructure than the options assessed here, reducing their near-term feasibility. It is also
435 critical to note that this analysis assumes that Oxford's coffee purchases remain at current
436 levels. Demand-side or "refrain" options aimed at influencing consumption patterns within
437 Oxford introduces additional complexity, for example through potential leakage effects (e.g.
438 consumers purchasing coffee elsewhere), or substitution towards other beverages that have
439 their own biodiversity footprints⁸³.

440

441 Discussion

442 Across the procurement network of a large organisation, we identify a pronounced loss of
443 traceability and transparency that prevents determination of the origin and composition of
444 many products. Yet, using coffee as a case study, we show that once quantity and sourcing
445 information become available, raw materials can be linked to production regions with distinct
446 biodiversity pressure profiles, helping identify partners for mitigation and conservation action.
447 This approach could be scaled to address other material impacts and highlights existing
448 collaborations as a practical means to begin addressing supply chain impacts.

449 However, scalability beyond products with simple supply chains and well-understood
450 biodiversity impacts is limited. While commodities such as agricultural or timber products have
451 comparatively well-characterised, spatially explicit pressure pathways - particularly via land
452 occupation and transformation - this becomes more challenging for goods with greater supply
453 chain complexity³⁶⁻³⁸. These constraints reflect broader limitations in inventory-level data
454 within LCA, where complex and opaque supply chains contribute to truncation and
455 completeness issues¹⁴⁻¹⁶. Additional barriers stem from remaining uncertainties in biodiversity
456 characterisation models within LCIA, particularly where pressures are diffuse and spatial
457 resolution is limited³¹.

458 Our findings suggest that stronger procurement practices are needed to incentivise collection
459 or sharing of biodiversity-relevant supply chain data. Addressing these challenges will require
460 clearer reporting expectations, standardised data sharing templates, and improved supplier
461 engagement. However, institutional reforms alone are insufficient. While carbon reporting
462 benefits from established standards and regulations, biodiversity reporting remains largely
463 voluntary, resulting in limited motivation for suppliers to provide biodiversity-relevant data⁸⁴⁻
464 ⁸⁷. This is further compounded by a lack of clear guidance on how responsibility for

465 biodiversity impacts should be allocated across supply chain actors, including whether
466 purchasing organisations are accountable for embedded impacts or whether responsibility
467 should be shared among producers, intermediaries, and end users¹⁶.

468 The importance of sourcing and raw material information is demonstrated through the regional
469 variation found in Oxford's coffee footprint; both in magnitude of impact and composition of
470 environmental pressures. Mitigation strategies must therefore be tailored to sourcing
471 geographies^{30,31}. In our coffee case study, for instance, the dominance of land use pressures in
472 East Africa indicates that land use-focused efforts in this region could be particularly beneficial.
473 More broadly, integrating spatially explicit LCIA outputs (Fig. 2) with our mitigation and
474 conservation matrix (Supplementary Information S4.1 Fig.S8) illustrates how footprinting can
475 support context-appropriate intervention design.

476 At the same time, biodiversity footprinting is subject to uncertainties, highlighting the need to
477 interpret LCIA outputs alongside other methods to ensure robust decision-making³⁶. In
478 particular, regionally averaged impact estimates and aggregate proxies such as material weight
479 or expenditure - commonly used in consumption-based footprinting - means procurement
480 substitutions towards products with lower biodiversity impacts may not be reflected in reported
481 footprints, weakening incentives for such changes. Consequently, greater use of on-the-ground
482 data to monitor biodiversity responses to interventions has the potential to substantially
483 improve estimates of impact mitigation outcomes.

484 This need for location-specific action emphasises an underused opportunity for universities.
485 For Oxford, existing collaborations span all inhabited continents and frequently overlap with
486 regions implicated in its supply chain impacts, offering trusted, on-the-ground connections with
487 farmers, cooperatives, NGOs, and researchers. Importantly, merging mitigation action with
488 pre-existing collaborations allows universities to align environmental sustainability strategies

489 with other elements of their mission, including global influence and equitable research
490 partnerships⁶⁰. In this sense, universities are positioned not only to reduce their own
491 biodiversity footprints and invest in compensatory actions for remaining impacts, but also to
492 generate positive biodiversity “handprints” through learning, innovation, and diffusion of
493 effective practices⁵¹. This approach is consistent with recent work emphasising the need for
494 universities to address both on-site activities and their wider supply chain impacts, while
495 contributing to broader shifts in how organisations engage with nature across global value
496 chains^{30,52}.

497 The Kenya case study illustrates how such collaborations can work in practice for a single
498 product and sourcing region (Fig. 1; Supplementary Information S4.3 Fig. S10). We
499 demonstrated how integrating biophysical pressures, social outcomes, collaborative
500 opportunities, and cost constraints could produce an actionable and context-appropriate
501 intervention scenario. Empirical tests of such scenarios would help evaluate their real-world
502 effectiveness and refine organisational approaches to supply chain mitigation. Finally, there is
503 substantial potential for collaborative action among universities, including coordination and
504 partnership between purchasing institutions and those located in impact regions, to drive
505 systemic change at scale.

506 Altogether, this study presents a scalable approach that moves beyond recognising supply chain
507 complexity toward enabling targeted biodiversity mitigation and conservation using practical,
508 context-appropriate actions. By combining bottom-up traceability assessment, location-
509 specific footprinting and adaptable implementation pathways, we bring to life a workflow for
510 applying the MCH to organisational supply chain impacts. While our case study example of
511 coffee is only one high-impact part of Oxford's supply chain, we believe the approach could be
512 scaled to other material impacts that organisations have on biodiversity - helping to bring an

513 organisation's value chain impacts into a credible Nature Positive-aligned strategy capable of
514 delivering transformative change³⁴.

515

516 Methods

517 Supply chain assessment

518 We focused on three procurement categories - research, operations and construction -
519 associated with supply chain activities that together account for most of the University of
520 Oxford's biodiversity footprint (Supplementary Information S1.2)⁷. Supplier and products were
521 derived from Oxford's Environmental Profit and Loss (EP&L) dataset, which quantifies
522 environmental impacts associated with university activities, and from item-level procurement
523 data provided by the Oxford Purchasing Department (OUP) for the 2022/23 financial year
524 (Supplementary Information S1.3).

525 All subcategories within research and construction were included. For operations, the five
526 highest-spend subcategories were selected because analysing all 29 was not feasible
527 (Supplementary Information S1.4 & S1.5). Within each subcategory, we identified the ten
528 highest-spend suppliers and their top three products, excluding miscoded or non-physical
529 items, and manually cross-checking to verify product identity. In total, 131 suppliers were
530 included: 50 from research and operations (ten in each of five subcategories), and 31 from
531 construction, with a reduced sample for the "Flooring" subcategory owing to a limited number
532 of physical commodities within the subcategory (Supplementary Information S1.6).

533 Traceability and transparency were assessed via a structured email request (with several
534 subsequent follow-ups) to each supplier for: (a) raw materials used in products, (b) sourcing
535 locations, and (c) availability of Life Cycle Assessment (LCA) data (Supplementary
536 Information S1.7). For each supplier, we recorded whether they responded, whether
537 information was provided, and the stated rationale for non-disclosure when applicable.
538 Suppliers were classified as distributors (entities reselling goods manufactured by others) or
539 manufacturers to characterise vertical complexity³⁹. For distributors, we also recorded whether

540 they were willing to contact upstream suppliers, providing an indicator of transparency beyond
541 the first tier.

542 Tracing and estimating biodiversity impacts

543 Invoices within the research, operations and construction categories reported financial
544 expenditure only, aggregated across multiple suppliers. As spend does not consistently reflect
545 material quantity, we used a separate category, food procurement, where both quantity and
546 weight were available, to demonstrate how organisations can trace the origins of a raw
547 commodity and estimate associated biodiversity impacts (Supplementary Information S2).

548 Food procurement data for University of Oxford cafeterias was provided by Compass Group
549 plc, which supplies 19 cafeterias across Oxford. Transaction records were extracted from the
550 company's internal procurement platform for 1 August 2022 to 31 July 2023. As nine additional
551 cafeterias are supplied by other contractors, total consumption was extrapolated to university
552 level (Supplementary Information S2.1).

553 Coffee was selected as the focal product because it is procured in raw material form, reducing
554 supply chain complexity relative to compound products, and because, despite representing a
555 small percentage of the University of Oxford's overall footprint (see Bull et al., 2022
556 Supplementary Information), it is a high-impact commodity for which complete elimination is
557 neither feasible nor socially desirable^{22,71,74} Continued procurement is necessary to meet
558 university demand (otherwise significant demand leakage to other outlets is likely), and to
559 support livelihoods in producing regions, where coffee contributes significantly to GDP and
560 employment⁴³⁻⁴⁵.

561 Coffee data was filtered to include roast, ground, and whole bean, with the total mass purchased
562 calculated by multiplying pack size (weight per pack) by the invoice quantity. Communication

563 with Compass confirmed that “Change Please Coffee” supplies Oxford’s cafeterias, and
564 sources from five countries: Columbia, Peru, Brazil, Honduras, and Burundi.

565 Biodiversity impacts were estimated using the LC-IMPACT Life Cycle Impact Assessment
566 (LCIA) framework, an extension of Life Cycle Assessment (LCA) methodologies providing
567 regionally specific endpoint biodiversity impact characterisation factors (CFs) and therefore
568 offering greater spatial resolution than alternative LCIA models such as ReCiPe^{32,33,46}. Whilst
569 several LCIA frameworks exist, each varying in their assumptions and CFs, relative
570 comparisons among sourcing regions remain robust when a consistent framework is applied.

571 Country-level midpoint environmental impact CFs were obtained from Poore & Nemecek
572 (2018), a global LCA meta-analysis of many agricultural products, including coffee, and
573 spanning multiple environmental impact categories (Supplementary Information S2.2)⁴⁷. To
574 reflect sourcing locations while accommodating data gaps, biodiversity footprint calculations
575 were conducted at a regional level (South America, Central America, and East Africa).
576 Midpoint environmental impact CFs were unavailable for three of the five sourcing countries
577 (Burundi, Honduras, and Peru) and for two environmental impact categories (acidification and
578 freshwater eutrophication) in Colombia. Kenya was the only country with complete CFs in
579 East Africa and was therefore used as a regional proxy, and missing Kenyan CFs for freshwater
580 eutrophication and acidification were substituted with global averages. To enable direct
581 comparison of different environmental impact profiles and total biodiversity footprints across
582 regions in the absence of sourcing quantities, the total coffee mass was divided equally among
583 the three regions.

584 LC-IMPACT expresses biodiversity loss as “Potentially Disappeared Fraction of species”
585 within a year (PDF.year), representing the fraction of species facing increased risk of
586 irreversible global extinction over time⁴⁶. Where necessary, multipliers from an alternative

587 model ReCiPe were used to convert midpoint environmental pressures into endpoint
588 compatible units, such as conversion of PO₄ to P equivalents (Supplementary Information
589 S2.1)³². Sensitivity analyses using ReCiPe and global CFs, and Spearman rank tests for
590 consistency in pressure hierarchies, are provided in the Supplementary Information S2.3.

591 Developing mitigation strategies

592 Supply chain mitigation and conservation opportunities were identified by mapping Oxford's
593 global biodiversity and conservation research collaborations. A survey containing up to 15
594 questions per collaboration was distributed to relevant Oxford researchers, who could submit
595 up to five collaborations each (Supplementary Information S3). Respondents reported
596 collaboration locations, partner institutions, research strength, and whether collaborations
597 could contribute to addressing supply chain impacts. A dedicated section focused on coffee to
598 identify linkages in producing regions. Where multiple respondents reported collaborations in
599 the same country, the country was coded as having mitigation potential if at least one
600 respondent answered 'yes' (Fig. 4b).

601 Scenario development: sustainable coffee transition in Kenya

602 We conducted a non-systematic literature review to identify key stages of the coffee supply
603 chain and combined these with survey findings to develop a matrix of potential interventions
604 aligned with the Mitigation and Conservation Hierarchy (Supplementary Information S4.1 Fig.
605 S8). LCIA results and literature were used to identify dominant environmental pressures at
606 cultivation and processing stages.

607 We selected Mount Elgon, Kenya as the hypothetical production region because Kenya hosts
608 Oxford's largest cluster of biodiversity and conservation research activities, and midpoint
609 characterisation factors for East African coffee in Poore & Nemecek (2018) are derived from
610 Kenyan LCA⁴⁷. Kenya also provides a more operationally feasible context for coordinated

611 supply chain mitigation due to its formal grower registration, cooperative-dominated
612 smallholder system, and strengthening EUDR-aligned traceability framework⁵⁷⁻⁵⁹.

613 A practical mitigation and conservation scenario was co-developed through two workshops
614 involving researchers from Strathmore University (Kenya) and Oxford University and two
615 Kenyan agronomists (all of whom are co-authors of this paper). The objective was to maintain
616 Oxford's annual procurement volume (3,468 kg yr⁻¹) while reducing environmental pressures
617 and generating social and research co-benefits. The objective was not to produce enough
618 biodiversity gain to compensate fully for negative impacts, as this would require gains and
619 losses to be specified in comparable units. That said, this could be done in future as on-the-
620 ground actions and associated monitoring programmes are implemented.

621 Before the first workshop, midpoint pressures were recalculated assuming all coffee was
622 sourced from Kenya. Intervention goals were defined for each impact category (e.g., land
623 restoration for land-use impacts; nutrient management for eutrophication) and candidate
624 measures were drawn from the literature-derived intervention matrix for evaluation by Kenyan
625 co-authors (Supplementary Information S4.1 Fig. S8).

626 During the first workshop, the participants identified the pressures addressed by each
627 intervention. Using information collected during the first workshop, interventions were
628 assessed using a structured qualitative process across three dimensions: biodiversity
629 enhancement, pressure reduction, and social benefit. Each dimension was then evaluated using
630 three predefined criteria: (1) scalability, defined as the potential to expand the interventions ;
631 (2) directness of impact, defined as the degree to which an intervention provides direct
632 outcomes through immediate and causal pathways; and (3) feasibility, defined as how
633 practically achievable the intervention is to deliver these dimensions, within the local context.
634 Each criterion was scored on a three-point ordinal scale (1-3). Criterion scores were aggregated

635 using an unweighted mean to generate a composite score for each dimension, which was then
636 translated into a categorical “traffic-light” rating of high (≥ 2.5), moderate (1.5–2.4) or minimal
637 (< 1.5) impact.

638 Preliminary scores were presented and discussed during the second workshop, where
639 participants reviewed and refined the assessments. Following a facilitated discussion, final
640 categorical ratings were agreed upon. Approximate intervention costs were discussed with the
641 participating agronomists, who provided indicative minimum and maximum cost estimates for
642 each intervention based on experience with comparable projects in the region.

643 Costs were classified as either upfront or annual. These results were used to construct a final
644 hypothetical scenario during the second workshop, including the target region and number of
645 farmers, a proposed core set of interventions, long-term extension options, research monitoring
646 pathways through Strathmore University and estimated costs. This process also produced a
647 transferable decision framework outlining sequential steps for developing tailored supply chain
648 mitigation scenarios, including defining scope and sourcing geography, buyer commitment and
649 budget, and options for monitoring and tracking progress (Supplementary Information S4.2
650 Fig. S9).

651

652 References

- 653 1. World Economic Forum. Nature Risk Rising: Why the Crisis Engulfing Nature
654 Matters for Business and the Economy. (WEF, 2020).
655
- 656 2. Taskforce on Nature-related Financial Disclosures. *TNFD*. Available at:
657 <https://tnfd.global/> (2020).
658
- 659 3. zu Ermgassen, S. O. S. E. *et al.* Are corporate biodiversity commitments consistent
660 with delivering ‘nature-positive’ outcomes? A review of ‘nature-positive’ definitions,
661 company progress and challenges. *J. Clean.Prod.* **379**, 134798 (2022).
662
- 663 4. World Wildlife Fund. *2024 Living Planet Report: A System in Peril*. (WWF, 2024).
664
- 665 5. Convention on Biological Diversity. COP15: Final text of Kunming-Montreal Global
666 Biodiversity Framework available in all UN languages. *Convention on Biological*
667 *Diversity* (2022). [https://www.cbd.int/article/cop15-final-text-kunming-montreal-gbf-](https://www.cbd.int/article/cop15-final-text-kunming-montreal-gbf-221222)
668 [221222](https://www.cbd.int/article/cop15-final-text-kunming-montreal-gbf-221222)
669
- 670 6. Lenzen, M. *et al.* International trade drives biodiversity threats in developing nations.
671 *Nature* **486**, 109–112 (2012).
672
- 673 7. Bull, J. W. *et al.* Analysis: the biodiversity footprint of the University of Oxford.
674 *Nature* **604**, 420–424 (2022).
675
- 676 8. Berger, J., Goedkoop, M. J., Broer, W., Nozeman, R., Grosscurt, C. D., Bertram, M. &
677 Cachia, F. *Common ground in biodiversity footprint methodologies for the financial*
678 *sector*. Paris (2018).
679
- 680 9. Kering. *Environmental Profit & Loss (EP&L) results*.
681 [https://www.kering.com/en/sustainability/measuring-our-impact/our-ep-l/ep-and-l-](https://www.kering.com/en/sustainability/measuring-our-impact/our-ep-l/ep-and-l-results/)
682 [results/](https://www.kering.com/en/sustainability/measuring-our-impact/our-ep-l/ep-and-l-results/) (2024).
683
- 684 10. Puma. *Clever Little Report*. [https://about.puma.com/sites/default/files/financial-](https://about.puma.com/sites/default/files/financial-report/2011/ar-2011.pdf)
685 [report/2011/ar-2011.pdf](https://about.puma.com/sites/default/files/financial-report/2011/ar-2011.pdf) (2011).
686
- 687 11. Thurston, M. & Eckelman, M. J. Assessing greenhouse gas emissions from university
688 purchases. *Int. J. Sustain. High. Educ.* **12**, 225–235 (2011).
689
- 690 12. Nature Positive Initiative. *Nature Positive Initiative* <https://www.naturepositive.org/>
691 (2023).
692

- 693 13. Sodhi, M. S. & Tang, C. S. Research opportunities in supply chain transparency. *Prod.*
694 *Oper. Manag.* **28**, 2946–2959 (2019).
695
- 696 14. Grimard, A., Lake, S., Mardas, N., Godar, J. & Gardner, T. A. *Supply chain*
697 *transparency network: State of play*. Supply Chain Transparency Network (2017).
698
- 699 15. Schaëfer, K., Kähkönen, A.-K. & Luzzini, D. Traceability in multi-tier supply chains:
700 insights from five case studies. *Supply Chain Manag.* **30**, 77–99 (2025).
701
- 702 16. Gardner, T. A. Transparency and sustainability in global commodity supply chains.
703 *World Dev.* **121**, 163–177 (2019).
704
- 705 17. Gualandris, J., Longoni, A., Luzzini, D. & Pagell, M. The association between supply
706 chain structure and transparency: A large-scale empirical study. *J. Oper. Manag.* **67**,
707 803–827 (2021).
708
- 709 18. TRASE. *Trase*. <https://trase.earth/>. (2024).
710
- 711 19. Kurth, T. *et al.* *The biodiversity crisis is a business crisis*. Boston Consulting Group &
712 World Wildlife Fund [https://web-](https://web-assets.bcg.com/fb/5e/74af5531468e9c1d4dd5c9fc0bd7/bcg-the-biodiversity-crisis-is-a-business-crisis-mar-2021-rr.pdf)
713 [assets.bcg.com/fb/5e/74af5531468e9c1d4dd5c9fc0bd7/bcg-the-biodiversity-crisis-is-](https://web-assets.bcg.com/fb/5e/74af5531468e9c1d4dd5c9fc0bd7/bcg-the-biodiversity-crisis-is-a-business-crisis-mar-2021-rr.pdf)
714 [a-business-crisis-mar-2021-rr.pdf](https://web-assets.bcg.com/fb/5e/74af5531468e9c1d4dd5c9fc0bd7/bcg-the-biodiversity-crisis-is-a-business-crisis-mar-2021-rr.pdf) (2021).
715
- 716 20. West, C., Titley, M., Croft, S., Molotoks, A., Simpson, J. & Green, J. *Assessing*
717 *tropical deforestation and biodiversity risk in Belgium’s agricultural commodity*
718 *supply chains*. Trase/Stockholm Environment Institute (2022).
719
- 720 21. Maron, M. *et al.* ‘Nature positive’ must incorporate, not undermine, the mitigation
721 hierarchy. *Nat. Ecol. Evol.* **8**, 14–17 (2024).
722
- 723 22. Science Based Targets Network (SBTN). *Science Based Targets Network*
724 <https://sciencebasedtargetsnetwork.org/> (2023).
725
- 726 23. André, H., Ljunggren Söderman, M. & Nordelöf, A. Resource and environmental
727 impacts of using second-hand laptop computers: A case study of commercial reuse.
728 *Waste Manag.* **88**, 268–279 (2019).
729
- 730 24. Khan, A. R. Transforming electronics lifecycle through expert refurbishment, quality
731 assurance, and transparent environmental impact. *Res. Corridor J. Eng. Sci.* **2**, 58–72
732 (2025).
733
- 734 25. Trusler, E. C., Davies, M., Spurrier, B. & Gould, S. J. Reusable glassware for routine
735 cell culture—a sterile, sustainable and affordable alternative to single-use plastics.

- 736 *Front. Sustain.* **5**, (2024).
737
- 738 26. Amaro, A., Pillay, S. & Grosscurt, C. *Utrecht University Biodiversity Footprint 2024:*
739 *Materiality assessment, footprint and scenario analysis.* Utrecht University (2024).
740
- 741 27. OECD. *Scaling Up Biodiversity-Positive Incentives: Delivering on Target 18 of the*
742 *Global Biodiversity Framework.* OECD Publishing (2025).
743 <https://doi.org/10.1787/19b859ce-en>
744
- 745 28. Baggaley, S. *et al.* *Nature positive for business.* IUCN (2023). <https://portals.iucn.org/>
746
- 747 29. Bang, A. *et al.* *A typology of corporate actions for a nature-positive future.*
748 *EcoEvoRxiv* (2025). <https://ecoevorxiv.org/repository/view/10429/>
749
- 750 30. Schlecht, V. *et al.* From local species monitoring to global value chain impacts: A
751 starting point for assessing biodiversity impacts of higher education institutions. *Biol.*
752 *Conserv.* **313**, 111613 (2025).
753
- 754 31. Bromwich, T. *et al.* Navigating uncertainty in life cycle assessment-based approaches
755 to biodiversity footprinting. *Methods. Ecol. Evol.* 1–18 (2025)
756
- 757 32. Huijbregts, M. A. J. *et al.* ReCiPe2016: a harmonised life cycle impact assessment
758 method at midpoint and endpoint level. *Int. J. Life Cycle Assess.* **22**, 138–147 (2016).
759
- 760 33. Hellweg, S., Benetto, E., Verones, F. & Wood, R. Life-cycle assessment to guide
761 solutions for the triple planetary crisis. *Nat. Rev. Earth Environ.* **4**, 471–486 (2023).
762
- 763 34. Booth, H., Milner-Gulland, E. J., McCormick, N. & Starkey, M. Operationalizing
764 transformative change for business in the context of Nature Positive. *One Earth* **7**
765 (2024).
766
- 767 35. Milner-Gulland, E. J. *et al.* Four steps for the Earth: mainstreaming the post-2020
768 global biodiversity framework. *One Earth* **4**, 75–87 (2021).
769
- 770 36. Crenna, E., Marques, A., La Notte, A. & Sala, S. Biodiversity Assessment of Value
771 Chains: State of the Art and Emerging Challenges. *Environ. Sci. Technol.* **54**, 9715–
772 9728 (2020).
773
- 774 37. Bode, C. & Wagner, S. M. Structural drivers of upstream supply chain complexity and
775 the frequency of supply chain disruptions. *J. Oper. Manag.* **36**, 215–228 (2018).
776

- 777 38. Choi, T. Y. & Hong, Y. Unveiling the structure of supply networks: case studies in
778 Honda, Acura, and DaimlerChrysler. *J. Oper. Manag.* **20**, 469–493 (2002).
779
- 780 39. Smith, P. M., Ross, E. S. & Smith, T. A case study of distributor-supplier business
781 relationships. *J. Bus. Res.* **39**, 39–44 (1997).
782
- 783 40. Kembro, J., Näslund, D. & Olhager, J. Information sharing across multiple supply
784 chain tiers: a Delphi study on antecedents. *Int. J. Prod. Econ.* **193**, 77–86 (2017).
785
- 786 41. Garcia-Torres, S., Rey-Garcia, M. & Sáenz, J. Enhancing sustainable supply chains
787 through traceability, transparency and stakeholder collaboration: a quantitative
788 analysis. *Bus. Strateg. Environ.* **33** (2024).
789
- 790 42. Ball, T.S., Dales, M., Eyres, A. et al. Food impacts on species extinction risks can
791 vary by three orders of magnitude. *Nat Food* **6**, 848–856 (2025).
792
- 793 43. Treanor, N. & Saunders, J. Tackling (illegal) deforestation in coffee supply chains:
794 What impact can demand-side regulations have? *Forest Trends* (2021). Available at:
795 [https://www.forest-trends.org/publications/tackling-illegal-deforestation-in-coffee-sup-](https://www.forest-trends.org/publications/tackling-illegal-deforestation-in-coffee-supply-chains-what-impact-can-demand-side-regulations-have/)
796 [ply-chains-what-impact-can-demand-side-regulations-have/](https://www.forest-trends.org/publications/tackling-illegal-deforestation-in-coffee-supply-chains-what-impact-can-demand-side-regulations-have/)
797
- 798 44. Fairtrade Foundation. *Coffee farmers*. Fairtrade Foundation (2021).
799 <https://www.fairtrade.org.uk/farmers-and-workers/coffee/>
800
- 801 45. Karuri, A. N. Adaptation of Small-Scale Tea and Coffee Farmers in Kenya to Climate
802 Change. in *African Handbook of Climate Change Adaptation* 1–19 (Springer, 2020).
803 https://doi.org/10.1007/978-3-030-42091-8_70-1.
804
- 805 46. Verones, F. et al. LC-IMPACT: A regionalized life cycle damage assessment method .
806 *J. Ind. Ecol.* **24**, 1201–1219 (2020).
807
- 808 47. Poore, J. & Nemecek, T. Reducing Food’s Environmental Impacts through Producers
809 and Consumers. *Science* **360**, 987–992 (2018).
810
- 811 48. Godar, J., Persson, U. M., Tizado, E. J. & Meyfroidt, P. Towards more accurate and
812 policy relevant footprint analyses: Tracing fine-scale socio-environmental impacts of
813 production to consumption. *Ecol. Econ.* **112**, 25–35 (2015).
814
- 815 49. Usva, K., Sinkko, T., Silvenius, F., Riipi, I. & Heusala, H. Carbon and water footprint
816 of coffee consumed in Finland—life cycle assessment. *Int. J. Life Cycle Assess.* **25**
817 (2020).
818

- 819 50. Hauschild, M. Z., Rosenbaum, R. K. & Olsen, S. I. *Life Cycle Assessment*. (Springer
820 International Publishing, 2018). <https://doi.org/10.1007/978-3-319-56475-3>.
821
- 822 51. Sandström, V., Kauppi, P. E., Scherer, L. & Kastner, T. Linking country level food
823 supply to global land and water use and biodiversity impacts: The case of Finland.
824 *Sci. Total Environ.* **575**, 33–40 (2017).
825
- 826 52. Alvarenga, R. A. F. *et al.* A framework for using the handprint concept in attributional
827 life cycle (sustainability) assessment. *J. Clean. Prod.* **265**, 121743 (2020).
828
- 829 53. De Felice, F., Rehman, M., Petrillo, A. & Baffo, I. Decoding the coffee supply chain:
830 A systematic review of stakeholders, sustainability opportunities, and challenges.
831 *Sustain. Fut.* **10**, 101105 (2025).
832
- 833 54. LiangHui, D. & Reeveerakul, N. Analysis of Critical Knowledge in a Coffee Supply
834 Chain. In *2019 Joint International Conference on Digital Arts, Media and Technology*
835 *with ECTI Northern Section Conference on Electrical, Electronics, Computer and*
836 *Telecommunications Engineering (ECTI DAMT-NCON)*. (2019).
837 <https://doi.org/10.1109/ecti-ncon.2019.8692290>.
838
- 839 55. Adams, M. & Ghaly, A. E. Maximizing sustainability of the Costa Rican coffee
840 industry. *J. Clean. Prod.* **15**, 1716–1729 (2007).
841
- 842 56. Robbins, P., Tripuraneni, V., Karanth, K. K. & Chhatre, A. Coffee, trees, and labor:
843 Political economy of biodiversity in commodity agroforests. *Ann. Am. Assoc. Geogr.*
844 **111**, 1046–1061 (2020).
845
- 846 57. Wambua, D. M., Ndirangu, S. N., Mogaka, H. & Gichimu, B. M. Determinants of the
847 produced coffee volumes and choice of marketing channels among smallholder coffee
848 farmers in Embu and Kirinyaga counties, Kenya. *Humanit. Soc. Sci. Commun.* **12**,
849 (2025).
850
- 851 58. Government of Kenya. *The Crops (Coffee) (General) Regulations*. *Kenyalaw.org* vol.
852 Legal Notice No. 102 of 2019 (2019).
853
- 854 59. TradeMark Africa. *Kenya Strengthens Traceability to Meet Deforestation-Free Market*
855 *Standards*. *Trademarkafrica.com* (2025). [https://trademarkafrica.com/kenya-](https://trademarkafrica.com/kenya-strengthens-traceability-to-meet-deforestation-free-market-standards/)
856 [strengthens-traceability-to-meet-deforestation-free-market-standards/](https://trademarkafrica.com/kenya-strengthens-traceability-to-meet-deforestation-free-market-standards/)
857
- 858 60. University of Oxford. *Environmental Sustainability Strategy*.
859 sustainability.admin.ox.ac.uk (2021).
860 <https://sustainability.admin.ox.ac.uk/environmental-sustainability-strategy>
861

- 862 61. Henry, P.-Y. *et al.* Integrating ongoing biodiversity monitoring: potential benefits and
863 methods. *Biodivers. Conserv.* **17**, 3357–3382 (2008).
864
- 865 62. Tschardtke, T. *et al.* Multifunctional shade-tree management in tropical agroforestry
866 landscapes - a review. *J. Appl. Ecol.* **48**, 619–629 (2011).
867
- 868 63. Ramni Jamnadass, Place, F., Torquebiau, E. & Dawson, I. Agroforestry, food and
869 nutritional security. *ResearchGate* (2013).
870 [https://www.researchgate.net/publication/254864845_Agroforestry_food_and_nutritio](https://www.researchgate.net/publication/254864845_Agroforestry_food_and_nutritional_security)
871 [nal_security](https://www.researchgate.net/publication/254864845_Agroforestry_food_and_nutritional_security)
872
- 873 64. Lehmann, L. M. *et al.* Productivity and economic evaluation of agroforestry systems
874 for sustainable production of food and non-food products. *Sustainability* **12**, 5429
875 (2020).
876
- 877 65. Jung, D. R. & Vendrametto, O. Agroforestry for food security and public health: A
878 comprehensive review. *Int. J. Environ. Res. Public Health* **22**, 645 (2025).
879
- 880 66. Duque-Dussán, E., Sanz-Urbe, J. R., Dussán-Lubert, C. & Banout, J. Thermophysical
881 properties of parchment coffee: New Colombian varieties. . *Food Process Eng.*
882 (2023). <https://doi.org/10.1111/jfpe.14300>.
883
- 884 67. Kipkorir, R. K., Muliro, P. & Muhoho, S. Effects of coffee processing technologies on
885 physico-chemical properties and sensory qualities of coffee. *Afr. J. Food Sci.* **9**, 230–
886 236 (2015).
887
- 888 68. Wariyo, A., Dejene, M. & Derso, E. Reaction of Southern coffee germplasms to
889 coffee berry disease (*Colletotrichum kahawae* Waller and Bridge), in Southern
890 Ethiopia. *Bioprocess Eng.* **9**, 58–69 (2025).
891
- 892 69. Bray, J. G. & Neilson, J. Reviewing the impacts of coffee certification programmes on
893 smallholder livelihoods. *Int. J. Biodivers. Sci. Ecosyst. Serv. Manag.* **13**, 216–232
894 (2017).
895
- 896 70. Kamau, M., Mose, L. & Fort, R. *The Impact of Certification on Smallholder Coffee*
897 *Farmers in Kenya: The case of 'UTZ' certification program* (2010).
898 [https://www.enterprise-development.org/wp-content/uploads/Kamau-Impact-of-](https://www.enterprise-development.org/wp-content/uploads/Kamau-Impact-of-Certification-in-Kenya-2010.pdf)
899 [Certification-in-Kenya-2010.pdf](https://www.enterprise-development.org/wp-content/uploads/Kamau-Impact-of-Certification-in-Kenya-2010.pdf)
900
- 901 71. White, T. B., Petrovan, S. O., Christie, A. P., Martin, P. A. & Sutherland, W. J. What is
902 the price of conservation? A review of the status quo and recommendations for
903 improving cost reporting. *BioScience* **72**, (2022).
904

- 905 72. Flyvbjerg, B. & Bester, D. W. The Cost-Benefit Fallacy: Why Cost-Benefit Analysis
906 Is Broken and How to Fix It. *Ssrn.com*
907 https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3918328 (2021).
908
- 909 73. Carwardine, J. et al. Conservation planning when costs are uncertain. *Conserv. Biol.*
910 **24**, 1529–1537 (2010).
911
- 912 74. Wynter, V., Milner-Gulland, E. J. & Poore, J. A global comparison of the biodiversity
913 impacts of coffee agricultural systems—From monoculture to diverse agroforestry.
914 *Agric. Syst.* **229**, 104449 (2025).
915
- 916 75. Perfecto, I. & Vandermeer, J. Spatial pattern and ecological process in the coffee
917 agroforestry system. *Ecol.* **89**, 915–920 (2008).
918
- 919 76. Nasiro, K. The benefits of agroforestry coffee production systems: A review. *World J.*
920 *Food Sci. Technol.* **8**, 86–105 (2024).
921
- 922 77. De Beenhouwer, M., Aerts, R. & Honnay, O. A global meta-analysis of the
923 biodiversity and ecosystem service benefits of coffee and cacao agroforestry. *Agric.*
924 *Ecosyst. Environ.* **175**, 1–7 (2013).
925
- 926 78. Moguel, P. & Toledo, V. M. Biodiversity conservation in traditional coffee systems of
927 Mexico. *Conserv. Biol.* **13**, 11–21 (1999).
928
- 929 79. Philpott, S. M. et al. Biodiversity loss in Latin American coffee landscapes: Review of
930 the evidence on ants, birds, and trees. *Conserv. Biol.* **22**, 1093–1105 (2008).
931
- 932 80. Jose, S. Agroforestry for ecosystem services and environmental benefits: An
933 overview. *Agrofor. Syst.* **76**, 1–10 (2009).
934
- 935 81. Smithsonian Migratory Bird Center. Smithsonian Bird Friendly. *Smithsonian's*
936 *National Zoo* <https://nationalzoo.si.edu/migratory-birds/bird-friendly> (2017).
937
- 938 82. Loconto, A. & Hatanaka, M. Participatory guarantee systems: Alternative ways of
939 defining, measuring, and assessing 'sustainability'. *Sociol. Ruralis* **58**, 412–432
940 (2017).
941
- 942 83. Balmford, A. et al. Time to fix the biodiversity leak. *Science* **387**, 720–722 (2025).
943
- 944 84. World Resources Institute. Greenhouse Gas Protocol. *World Resources Institute*
945 <https://www.wri.org/initiatives/greenhouse-gas-protocol> (2024).
946

947 85. British Universities Finance Directors Group & Higher Education Procurement
948 Association. Embedding nature and biodiversity into higher education procurement.
949 *BUFDG* <https://www.bufdg.ac.uk/> (2023).

950

951 86. International Organization for Standardization. ISO 14064-1:2018 Greenhouse gases
952 — Part 1: Specification with guidance at the organization level for quantification and
953 reporting of greenhouse gas emissions and removals. (*International Organization for*
954 *Standardization, 2018*).

955

956 87. International Organization for Standardization. ISO 14040:2006 Environmental
957 management — Life cycle assessment — Principles and framework. (*International*
958 *Organization for Standardization, 2006*).

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967 É. F., T. B., S. z. E., and E. J. M.-G. conceived the study. É. F. conducted the traceability
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970 B. É. F. developed the mitigation/conservation coffee matrix in collaboration with A. K., S. T.
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