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**Narrower Portfolios, Shared Mills: Non-random Restructuring of Corporate Palm Oil
Mill Disclosures**

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Supplementary Note 1: Corporate evidence on supply-chain restructuring.

PZ Cussons. PZ Cussons explicitly acknowledged that supplier-provided mill lists do not always correspond closely to the mills associated with its own supply. In its *Our 2023 Palm Oil Action Plan: July 2022 Progress Update*, the company reported that some derivative suppliers were “still only providing global mill lists for their entire supply” and stated that improved supplier information would allow it “to focus on the oil that is in our supply only” (pp. 3, 5). The company further identified a shift from global mill lists toward mill lists representing its own supply as important for improving traceability to plantation. This provides a direct example of why publicly disclosed mill lists may represent a broader set of potential upstream connections rather than transaction-specific mill-to-company flows.

Source:

PZ Cussons, *Our 2023 Palm Oil Action Plan: July 2022 Progress Update*.
https://www.pzcussons.com/wp-content/uploads/2022/07/Palm-Oil-Action-Plan_July2022_v2.pdf (accessed 27 September 2026).

Mars. Mars explicitly described reducing the number of mills in its palm oil supply chain as part of its *Palm Positive Plan*. In 2020, the company reported that it was reducing its mill network from approximately 1,500 mills to fewer than 100 by 2021, while establishing longer-term relationships with a smaller number of suppliers meeting its environmental, social, and ethical expectations. Mars described this as a “radical simplification” of its supply chain intended to improve mapping, monitoring, and supplier engagement. The company also highlighted its adoption of the UniFuji 1:1:1 model, in which palm oil is supplied through a segregated pathway linking one plantation, one mill, and one refinery.

Source:

Mars, Incorporated. *Mars Palm Positive Plan Delivers Deforestation-Free Palm Oil Supply Chain*. Press release, 6 October 2020. <https://www.mars.com/news-and-stories/press-releases/mars-palm-positive-plan> (accessed 27 September 2026).

Unilever. Unilever explicitly identified reducing the number of palm oil mills as a means of improving traceability and risk management. In its *Annual Report and Accounts 2020*, the company stated that working with fewer palm oil mills would allow it to better manage traceability and risk, and reported a plan to reduce its palm oil mill network from approximately 1,600 to 500 mills by 2023 (p. 29).

Source:

Unilever PLC. *Annual Report and Accounts 2020* (Unilever PLC, London, 2021).
<https://assets.unilever.com/files/92ui5egz/production/e665693f2bd2efbbde5658baf84043df7937cfd7.pdf/annual-report-and-accounts-2020.pdf>

Supplementary Note 2: Extended Methods.

Compilation of company mill lists

We compiled publicly available palm oil mill lists for companies classified as consumer goods manufacturers in the membership database of the Roundtable on Sustainable Palm Oil (RSPO). Under RSPO Resolution GA15-6b¹, members involved in primary procurement are required to publicly disclose their supplying mills, including information such as mill name, country, geographic coordinates, and parent company. Subsequent RSPO guidance further encourages supply chain actors sourcing indirectly through intermediaries to publish supplying mill lists through the RSPO online platform. Downstream manufacturers commonly obtain mill information from direct suppliers and other intermediaries as part of traceability exercises for their palm oil supply chains. In some cases, however, suppliers provide broad global mill lists rather than lists specific to the company's actual supply (Supplementary Note 1). As of September 2025, 35 out of 975 consumer goods manufacturers had published at least one mill list on the RSPO platform, although the available lists for individual companies rarely spanned more than three years and were therefore not suitable for longitudinal analysis. We therefore supplemented these data with mill lists obtained from corporate sustainability reports, official company websites, and PalmWatch, a collaborative data science project developed by Inclusive Development International and the University of Chicago Data Science Institute (Supplementary Table 11).

Using these sources, we identified companies for which mill lists were available for both 2020–2021 (P1) and 2023–2024 (P2), enabling comparison between periods. Our analysis focused on companies with broad, internationally distributed palm oil sourcing portfolios. We therefore retained companies for which at least 100 mills in P1 could be successfully matched to the Universal Mill List (UML; see below). This criterion also reduced the potential influence of incomplete supply-chain coverage during the early phase of mill-list disclosure. One additional company was excluded because all five of its mill lists published between 2021 and 2024 were identical, providing no observable temporal variation in its disclosed sourcing portfolio. The final dataset comprised 20 companies headquartered in European countries, the United States, Mexico, and Japan, serving diverse markets for palm oil-related products (Supplementary Table 1).

The temporal coverage of the mill lists varied across companies and years (Supplementary Table 11). Lists represented different sourcing periods, including half-year periods (January–June or July–December), full years, or single time-point snapshots. When multiple lists were available, we selected the earliest available list for P1 and the latest available list for P2. Where possible, we used two half-year lists to represent a given year rather than a single list. To improve comparability within companies, full-year lists were paired with two half-year lists when temporal coverage differed between the study periods, whereas half-year lists within the same year were generally highly similar. Snapshot lists were paired with either a full-year or a half-year list depending on data availability. In total, we analyzed 58 mill lists (Supplementary Table 11).

Construction of bipartite company–mill networks

To enable cross-company comparison and network analysis, we matched all mills to a common reference dataset (*i.e.*, the Universal Mill List (UML)²). The UML integrates data contributed by

companies and organizations within the palm oil sector, including RSPO, and provides standardized information on mill names, parent companies, geographic coordinates, RSPO certification status, and unique identifiers (UML IDs) consisting of the prefix “PO” followed by 10 digits. The database is regularly updated and widely used for supply chain mapping and traceability analyses. We used the January 2026 version of the UML, which contained 2,382 uniquely identified mills worldwide, including 1,472 in Indonesia and 500 in Malaysia. These totals were broadly comparable to estimates from country-specific sources^{3,4}, although differences in reporting periods and definitions precluded a precise assessment of UML coverage.

From the 58 company mill lists, we obtained 110,044 mill records (Supplementary Figure 2). Some of them represented repeated appearances of the same mill within a list, for example when products from a mill were sourced through multiple suppliers or intermediaries. Of these records, 81.9% (90,169) were associated with valid UML IDs present in the reference dataset. Records with IDs not found in the UML (n = 241) were excluded from further steps. For records lacking UML IDs, we assigned UML IDs through exact matching of mill names (11.0%; 12,110 records) and geographic proximity (5.9%; 6,529 records). For the latter, we assigned the UML ID of the nearest mill within 1 km. Name matching was prioritized over geographic matching because some lists contained erroneous coordinates (e.g., missing decimals, swapped latitude and longitude values, or low precision). Overall, valid UML IDs were assigned to 98.9% of the records (108,808) (Supplementary Table 12; Supplementary Figure 2).

Records with valid UML IDs were grouped by company and study period (P1, 2020–2021 and P2, 2023–2024) and aggregated to 48,173 unique company–mill–period combinations to construct a binary incidence matrix (company × mill) for each period, where each entry indicates whether a given mill appeared in the company’s list for that period. Because the set of mills differed between the periods (P1, 2,038 mills; P2, 2,059 mills), we restricted the analysis to mills present in both periods (1,863 mills) to avoid ambiguity in interpretation. Mills appearing in only one period may reflect either supply chain decisions (e.g., addition or replacement) or external factors such as mill opening or closure, which cannot be distinguished. This filtering step resulted in a modest reduction in the number of mills per company (mean ± s.d.: $2.9 \pm 2.6\%$; Mills (all) vs. Mills (shared) in Supplementary Table 12). These matrices formed the basis for subsequent analyses of supply chain structure and its temporal changes.

Deforestation around mills

We estimated deforestation around mills using the deforestation-year layer of the Tropical Moist Forest (TMF) dataset (v1_2024), produced by the Joint Research Centre (JRC), which maps annual forest loss at 30-m resolution across tropical regions^{5,6}. Mill coordinates were obtained from the UML and deforestation around mills was assessed in Google Earth Engine—a cloud-computing platform for geospatial analysis. For each mill, annual deforested area from 2016 to 2020 was calculated within circular buffers of 10, 20, and 50 km by summing the area of forest-loss pixels using zonal statistics. Annual values were then summed to obtain cumulative deforested area over the five-year period. The 20-km measure was used in the primary analysis, and the 10- and 50-km measures were used in sensitivity analyses (see below).

Potential biodiversity importance around mills

We quantified potential biodiversity importance around mills using the Species Threat Abatement and Restoration (STAR) metric^{7,8}. The STAR metric is designed to indicate how habitat loss and restoration at the site influence extinction risk by integrating information on threatened species present at the site, their extinction risk, and their global distributions. We used a global raster of STAR scores at ~5 km resolution, and calculated, for each mill, the proportion of high-STAR areas within the same circular buffers of 10, 20, and 50 km used for deforestation. High-STAR areas were defined as the top 10% of STAR values globally. This threshold-based metric was adopted because STAR values are highly skewed, making mean-based measures less informative for identifying areas of concentrated conservation importance. STAR values were extracted using area-weighted raster extraction, accounting for partial pixel coverage within buffers. Marine areas were excluded from the analysis.

RSPO certification of mills

We extracted mill certification status from the UML. The dataset distinguished four certification categories based on the RSPO supply chain system: Identity Preserved (IP), in which certified palm oil is physically separated and traceable to a single certified source; Mass Balance (MB), which permits mixing of certified and non-certified palm oil while administratively monitoring certified volumes; mixed IP/MB supply; and uncertified mills⁹. Although updated certification status and audit records are publicly available through the RSPO website, historical certification records were not consistently available for all mills. Therefore, we used the certification status recorded in the January 2026 UML dataset for all analyses.

Statistical analyses

All analyses were conducted in R version 4.6.1¹⁰. The code and data for the analyses are available at Zenodo (xxxxx).

1) Comparison of P1 and P2 networks

We compared the structural properties of the company–mill bipartite networks between P1 and P2 (Supplementary Table 2). Degree centralization was calculated separately for companies and mills, following Freeman¹¹, to assess the extent to which connections were concentrated among a subset of nodes. This metric captures heterogeneity in node degree relative to the most highly connected node and is normalized by the theoretical maximum for a network of the same size. High mill-side degree centralization indicates that connections are concentrated among a limited number of mills, whereas most other mills have fewer connections. Because mill-side degree centralization is influenced by the matrix dimensions and the degree distribution among the companies, we compared the observed value for each period with values from 999 null matrices generated under the c0 model using the *oecosimu()* function in the *vegan* package¹². The c0 model preserved the matrix dimensions and column sums, and thus the number of mills connected to each company and the total number of links, while randomizing the identities of the connected mills.

We further calculated the proportion of high-degree mills connected to each company in P1 and P2. High-degree mills were defined as the top 20% of mills ranked by degree within each period. Mills tied at the 20% cutoff were fractionally weighted so that high-degree mills represented exactly 20% of all mills. Because mill-degree distributions differed between periods, the degree thresholds were 19 in

P1 and 15 in P2. We examined the association between the proportional change in each company's mill-list length and the change in its proportion of high-degree mills using Spearman's rank correlation. We also conducted the analysis with different proportions (10% and 30% instead of 20%); the results were qualitatively consistent (results not shown).

2) Comparison of the observed P2 network and randomized P2 networks

To assess whether the observed mill-side degree centralization in P2 could arise from random turnover in company–mill associations from P1, we conducted a randomization analysis. For each company, we identified mills that were retained, dropped, or newly added between the two periods (Figure 1C). Randomized P2 networks were generated by randomly removing from each company's P1 network the same number of mills as were empirically dropped and randomly adding the same number of new mills from mills not connected to the company in P1. This procedure preserves the observed numbers of retained, dropped, and added mills for each company while removing non-random selection of specific mills. We generated 999 randomized networks, and the resulting mill-side degree centralization values were compared with the observed P2 value.

3) Factors associated with link retention and addition

To examine factors associated with changes in company–mill links between P1 and P2, we fitted generalized linear mixed models (GLMMs) with a binomial error distribution and logit link using the *glmer()* function in the *lme4* package¹³. Separate models were fitted for link retention and addition. The retention model included links present in P1, which were classified as retained if they persisted in P2 and dropped otherwise. The addition model included company–mill pairs unconnected in P1, which were classified as added if a link was present in P2 and not added otherwise.

Mill-level predictors were degree in P1 (Supplementary Figure 3A), RSPO certification status (Supplementary Figure 3B), deforested area (Supplementary Figure 3C), and the proportion of the surrounding area within the highest 10% of STAR values (Supplementary Figure 3D). Deforested area and high-STAR area were calculated within a 20-km radius of each mill. Mill degree and deforested area were natural-log-transformed. Company identity was included as a fixed categorical effect, with P&G as the reference level. Country of the mill and mill identity were included as random intercepts to account for non-independence among observations. Pairwise correlations among continuous predictors were low ($|r| < 0.30$), and generalized variance inflation factors indicated no problematic multicollinearity (Supplementary Tables 13–16). Model-predicted probabilities and their 95% confidence intervals were calculated and visualized using the *ggeffects* package¹⁴. To visualize unadjusted relationships in a separate figure, observed binary outcomes were aggregated into adaptive bins, and the proportion of retained or added links was calculated for each bin (Supplementary Figure 1).

Reported palm fruit sourcing distances vary among studies: a radius of 50 km is often used as an approximate maximum sourcing extent, whereas empirical studies report mean sourcing distances of approximately 9–25 km^{15–17}. We therefore used a 20-km buffer for the main analyses (Supplementary Tables 3, 4) and repeated the analyses using 10- and 50-km buffers as sensitivity tests. The results were qualitatively similar across buffer sizes (Supplementary Tables 5–8).

To examine whether the estimated effect of deforestation was obscured by differences among countries, we additionally partitioned deforested area into the country mean and each mill's deviation from that mean, while retaining country as a random effect. This allowed the within-country

association between local deforestation and link turnover to be estimated separately from broader country-level differences (Supplementary Tables 9, 10).

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Supplementary Table 1: List of target companies.

Company	Short name	Country	Product category	Europe	Market N.America	Other	Volume (2021)	Volume (2024)
Corporativo Bimbo S.A. de C.V.	Bimbo	Mexico	FG	0.13	0.18	0.69	112,600	144,439
Blommer Chocolate	Blommer	USA	FG	0.00	1.00	0.00	18,415	14,938
Colgate-Palmolive Company	Colgate	USA	HPCG	0.04	0.08	0.88	210,440	237,299
Danone	Danone	France	FG	0.12	0.55	0.33	67,498	58,503
Ferrero International S.A.	Ferrero	Luxembourg	FG	0.65	0.16	0.19	236,486	268,900
The Hershey Company	Hershey	USA	FG	0.00	0.93	0.07	33,392	34,093
Kao Corporation	Kao	Japan	HPCG	0.08	0.00	0.92	495,434	518,634
L'Oréal	L'Oréal	France	HPCG	0.52	0.15	0.33	90,313	100,484
Lion Corporation	Lion	Japan	HPCG	0.00	0.00	1.00	32,316	25,617
Mars, Incorporated	Mars	USA	FG	0.46	0.31	0.23	72,059	98,232
Meiji Holdings Co., Ltd.	Meiji	Japan	FG	0.00	0.13	0.87	20,480	22,159
Mondelez International, Inc	Mondelez	USA	FG	0.33	0.20	0.47	343,451	368,732
Nestlé S.A.	Nestlé	Switzerland	FG	0.08	0.07	0.85	467,744	425,994
Nouryon Holdings BV	Nouryon	Netherlands	OC	NA	NA	NA	19,202	13,649
The Procter & Gamble Company	P&G	USA	FG	0.40	0.21	0.39	152,304	277,748
PepsiCo	PepsiCo	USA	FG	0.01	0.01	0.98	437,226	400,000
PZ Cussons Plc	PZC	UK	HPCG	0.22	0.00	0.78	48,547	44,373
Reckitt Benckiser PLC	Reckitt	UK	HPCG	0.02	0.07	0.91	161,988	161,045
Royal FrieslandCampina N.V.	RFC	Netherlands	FG	0.35	0.00	0.65	140,900	126,046
Unilever PLC	Unilever	UK	FG, HPCG	0.08	0.07	0.85	902,449	809,961

Notes. Short name indicates abbreviated company names used throughout the tables and figures. Product categories indicate the main business sector in the palm oil supply chain (FG, food goods manufacturers; HPCG, home and personal care goods manufacturers; OC, oleochemicals). The Market columns show the regional distribution of each company's palm oil-related sales. Volumes for 2021 and 2024 indicate the total volume of palm oil (tonnes) purchased by each company in the respective years. Company names, product categories, regional distribution, and purchase volumes are based on Annual Communication of Progress (ACOP) reports available on the Roundtable on Sustainable Palm Oil (RSPO) website.

Supplementary Table 2: Network structure in P1 (2020–2021), P2 (2023–2024), and randomized P2 networks.

Metric	P1	P2	Randomized P2 (mean $\pm$ SD)
Degree centralization (companies)	0.272	0.354	
Degree centralization (mills)	0.334	0.456	0.334 $\pm$ 0.032
Network density	0.683	0.567	
Mean degree (companies)	1,273	1,056	
SD degree (companies)	287	549	
Mean degree (mills)	13.661	11.338	
SD degree (mills)	5.488	4.363	2.403 $\pm$ 0.030

Notes. Networks were constructed from bipartite company–mill matrices restricted to mills observed in both periods to ensure comparability between periods ($n = 1,863$ mills). Values for randomized P2 networks are means $\pm$ SD across 999 randomizations. Blank cells indicate metrics that were constrained to match the corresponding observed P2 values.

Supplementary Table 3: Results of the retention model.

Term	OR	95% CI	Estimate	SE	z	p
Intercept	0.135	[0.06, 0.31]	−2.000	0.420	−4.762	0.000***
Company: Lion	1.132	[0.85, 1.51]	0.124	0.148	0.837	0.402
Company: Ferrero	0.010	[0.01, 0.01]	−4.571	0.149	−30.603	0.000***
Company: PepsiCo	2.999	[2.20, 4.09]	1.098	0.158	6.947	0.000***
Company: Unilever	0.016	[0.01, 0.02]	−4.128	0.130	−31.683	0.000***
Company: Kao	0.742	[0.54, 1.02]	−0.299	0.163	−1.838	0.066
Company: Bimbo	0.926	[0.71, 1.20]	−0.077	0.133	−0.582	0.560
Company: Colgate	0.040	[0.03, 0.05]	−3.218	0.128	−25.128	0.000***
Company: PZC	3.298	[2.40, 4.52]	1.193	0.161	7.395	0.000***
Company: Hershey	0.257	[0.20, 0.33]	−1.358	0.131	−10.390	0.000***
Company: L'Oréal	0.246	[0.19, 0.32]	−1.402	0.140	−10.003	0.000***
Company: Reckitt	2.228	[1.62, 3.06]	0.801	0.161	4.965	0.000***
Company: Mars	0.003	[0.00, 0.00]	−5.676	0.165	−34.489	0.000***
Company: Nestlé	2.755	[2.02, 3.76]	1.014	0.159	6.386	0.000***
Company: RFC	0.075	[0.06, 0.10]	−2.595	0.126	−20.566	0.000***
Company: Meiji	5.013	[3.31, 7.59]	1.612	0.212	7.617	0.000***
Company: Nouryon	0.008	[0.01, 0.01]	−4.850	0.142	−34.137	0.000***
Company: Blommer	0.184	[0.14, 0.24]	−1.690	0.136	−12.468	0.000***
Company: Mondelez	0.961	[0.73, 1.26]	−0.040	0.137	−0.291	0.771
Company: Danone	0.003	[0.00, 0.00]	−5.828	0.166	−35.119	0.000***
Degree (log)	4.597	[3.91, 5.40]	1.525	0.082	18.592	0.000***
STAR (20 km)	1.001	[0.76, 1.32]	0.001	0.140	0.007	0.995
DF (log ha, 20 km)	1.007	[0.93, 1.09]	0.007	0.041	0.161	0.872
Certification: MB	1.328	[1.08, 1.64]	0.284	0.106	2.664	0.008**
Certification: IP/MB	2.846	[2.21, 3.66]	1.046	0.129	8.117	0.000***
Certification: IP	13.780	[10.10, 18.81]	2.623	0.159	16.535	0.000***

Notes. Company is included as a categorical variable, with P&G as the reference level. DF (log ha, 20 km) denotes log-transformed deforestation area (ha) within a 20-km buffer. Certification is a categorical variable with uncertified as the reference level; other categories include MB (mass balance), IP (identity preserved), and IP/MB (mixed supply).

Supplementary Table 4: Results of the addition model.

Term	OR	95% CI	Estimate	SE	z	p
Intercept	0.064	[0.03, 0.16]	-2.742	0.449	-6.103	0.000***
Company: Lion	0.814	[0.61, 1.09]	-0.206	0.149	-1.379	0.168
Company: Ferrero	0.032	[0.02, 0.04]	-3.453	0.170	-20.298	0.000***
Company: PepsiCo	7.966	[5.23, 12.14]	2.075	0.215	9.646	0.000***
Company: Unilever	0.024	[0.01, 0.05]	-3.711	0.317	-11.700	0.000***
Company: Kao	1.236	[0.96, 1.60]	0.212	0.131	1.615	0.106
Company: Bimbo	0.056	[0.03, 0.12]	-2.881	0.383	-7.520	0.000***
Company: Colgate	0.109	[0.08, 0.15]	-2.212	0.166	-13.347	0.000***
Company: PZC	4.820	[3.23, 7.19]	1.573	0.204	7.702	0.000***
Company: Hershey	0.166	[0.12, 0.23]	-1.798	0.165	-10.927	0.000***
Company: L'Oréal	0.387	[0.30, 0.50]	-0.948	0.135	-7.032	0.000***
Company: Reckitt	2.863	[2.08, 3.93]	1.052	0.162	6.486	0.000***
Company: Mars	0.034	[0.02, 0.05]	-3.391	0.177	-19.153	0.000***
Company: Nestlé	6.405	[4.37, 9.39]	1.857	0.195	9.518	0.000***
Company: RFC	0.233	[0.17, 0.32]	-1.456	0.165	-8.830	0.000***
Company: Meiji	5.475	[4.04, 7.41]	1.700	0.154	11.005	0.000***
Company: Nouryon	0.071	[0.05, 0.10]	-2.643	0.176	-14.998	0.000***
Company: Blommer	0.203	[0.15, 0.27]	-1.595	0.142	-11.203	0.000***
Company: Mondelez	1.058	[0.73, 1.53]	0.056	0.188	0.298	0.766
Company: Danone	0.033	[0.02, 0.05]	-3.409	0.189	-18.062	0.000***
Degree (log)	2.021	[1.78, 2.30]	0.703	0.065	10.752	0.000***
STAR (20 km)	0.881	[0.64, 1.22]	-0.127	0.167	-0.761	0.447
DF (log ha, 20 km)	0.991	[0.90, 1.09]	-0.009	0.050	-0.176	0.860
Certification: MB	1.172	[0.90, 1.53]	0.158	0.135	1.170	0.242
Certification: IP/MB	1.267	[0.92, 1.75]	0.237	0.165	1.434	0.152
Certification: IP	4.184	[2.78, 6.30]	1.431	0.209	6.844	0.000***

Notes. Company is included as a categorical variable, with P&G as the reference level. DF (log ha, 20 km) denotes log-transformed deforestation area (ha) within a 20-km buffer. Certification is a categorical variable with uncertified as the reference level; other categories include MB (mass balance), IP (identity preserved), and IP/MB (mixed supply).

Supplementary Table 5: Results of the retention model using a 10-km buffer.

Term	OR	95% CI	Estimate	SE	z	p
Degree (log)	4.610	[3.93, 5.41]	1.528	0.082	18.630	0.000***
STAR (10 km)	1.133	[0.89, 1.43]	0.125	0.120	1.037	0.300
DF (log ha, 10 km)	1.032	[0.97, 1.10]	0.032	0.031	1.018	0.309
Certification: MB	1.328	[1.08, 1.64]	0.284	0.106	2.667	0.008**
Certification: IP/MB	2.842	[2.21, 3.66]	1.045	0.129	8.098	0.000***
Certification: IP	13.702	[10.04, 18.70]	2.618	0.159	16.496	0.000***

Notes. The model uses a 10-km buffer (instead of 20 km) to evaluate the effects of deforestation (DF) and species extinction risk (STAR). Other variables are defined as in Supplementary Table 3. Company fixed effects were included but are not shown.

Supplementary Table 6: Results of the retention model using a 50-km buffer.

Term	OR	95% CI	Estimate	SE	z	p
Degree (log)	4.577	[3.89, 5.38]	1.521	0.082	18.469	0.000***
STAR (50 km)	0.784	[0.56, 1.10]	-0.243	0.171	-1.421	0.155
DF (log ha, 50 km)	0.989	[0.89, 1.10]	-0.011	0.056	-0.189	0.850
Certification: MB	1.319	[1.07, 1.63]	0.277	0.106	2.608	0.009**
Certification: IP/MB	2.818	[2.19, 3.63]	1.036	0.129	8.043	0.000***
Certification: IP	13.799	[10.11, 18.83]	2.625	0.159	16.542	0.000***

Notes. The model uses a 50-km buffer (instead of 20 km) to evaluate the effects of deforestation (DF) and species extinction risk (STAR). Other variables are defined as in Supplementary Table 3. Company fixed effects were included but are not shown.

Supplementary Table 7: Results of the addition model using a 10-km buffer.

Term	OR	95% CI	Estimate	SE	z	p
Degree (log)	2.018	[1.78, 2.29]	0.702	0.065	10.739	0.000***
STAR (10 km)	1.000	[0.75, 1.33]	0.000	0.145	0.002	0.998
DF (log ha, 10 km)	1.012	[0.94, 1.09]	0.012	0.038	0.318	0.751
Certification: MB	1.174	[0.90, 1.53]	0.161	0.135	1.187	0.235
Certification: IP/MB	1.278	[0.93, 1.77]	0.245	0.165	1.489	0.137
Certification: IP	4.170	[2.77, 6.28]	1.428	0.209	6.830	0.000***

Notes. The model uses a 10-km buffer (instead of 20 km) to evaluate the effects of deforestation (DF) and species extinction risk (STAR). Other variables are defined as in Supplementary Table 4. Company fixed effects were included but are not shown.

Supplementary Table 8: Results of the addition model using a 50-km buffer.

Term	OR	95% CI	Estimate	SE	z	p
Degree (log)	2.025	[1.78, 2.30]	0.706	0.066	10.750	0.000***
STAR (50 km)	0.818	[0.56, 1.20]	-0.200	0.196	-1.024	0.306
DF (log ha, 50 km)	0.959	[0.84, 1.09]	-0.042	0.065	-0.650	0.515
Certification: MB	1.174	[0.90, 1.53]	0.160	0.136	1.181	0.238
Certification: IP/MB	1.254	[0.91, 1.73]	0.227	0.165	1.371	0.170
Certification: IP	4.150	[2.75, 6.26]	1.423	0.209	6.799	0.000***

Notes. The model uses a 50-km buffer (instead of 20 km) to evaluate the effects of deforestation (DF) and species extinction risk (STAR). Other variables are defined as in Supplementary Table 4. Company fixed effects were included but are not shown.

Supplementary Table 9: Results of the retention model including within- and between-country components of deforestation.

Term	OR	95% CI	Estimate	SE	z	p
Degree (log)	4.590	[3.91, 5.39]	1.524	0.082	18.593	0.000***
STAR (20 km)	1.002	[0.76, 1.32]	0.002	0.140	0.018	0.986
DF (within)	0.996	[0.92, 1.08]	−0.004	0.042	−0.097	0.923
DF (country mean)	1.236	[0.89, 1.72]	0.212	0.169	1.259	0.208
Certification: MB	1.325	[1.08, 1.63]	0.281	0.106	2.644	0.008**
Certification: IP/MB	2.833	[2.20, 3.65]	1.041	0.129	8.077	0.000***
Certification: IP	13.757	[10.09, 18.76]	2.622	0.158	16.557	0.000***

Notes. DF (within) denotes the deviation in log-transformed deforestation area (ha) within a 20-km buffer from the country mean (within-country effect), and DF (country mean) denotes the country-level mean deforestation (between-country effect). See Supplementary Table 3 for details of other fixed effects. Estimates and associated statistics for the company fixed effect are not shown.

Supplementary Table 10: Results of the addition model including within- and between-country components of deforestation.

Term	OR	95% CI	Estimate	SE	z	p
Degree (log)	2.021	[1.78, 2.30]	0.704	0.065	10.756	0.000***
STAR (20 km)	0.881	[0.64, 1.22]	−0.126	0.167	−0.757	0.449
DF (within)	1.002	[0.91, 1.11]	0.002	0.052	0.036	0.972
DF (country mean)	0.874	[0.62, 1.23]	−0.135	0.174	−0.777	0.437
Certification: MB	1.175	[0.90, 1.53]	0.161	0.135	1.191	0.234
Certification: IP/MB	1.273	[0.92, 1.76]	0.242	0.165	1.463	0.143
Certification: IP	4.186	[2.78, 6.31]	1.432	0.209	6.852	0.000***

Notes. DF (within) denotes the deviation in log-transformed deforestation area (ha) within a 20-km buffer from the country mean (within-country effect), and DF (country mean) denotes the country-level mean deforestation (between-country effect). See Supplementary Table 4 for details of other fixed effects. Company fixed effects were included but are not shown.

Supplementary Table 11: Mill lists published by companies used in this study.

Company	Year	Period	ID	GPS	Source	Last accessed
Bimbo	2020	F	Y	Y	Bimbo (2020)	2026.03.06
Bimbo	2024	F	Y	Y	Bimbo (2024)	2026.03.06
Blommer	2021	H1	N	Y	RSPO	2026.04.20
Blommer	2024	H1	N	Y	RSPO	2026.04.20
Colgate	2020	H1	Y	Y	PalmWatch	2026.03.06
Colgate	2020	H2	Y	Y	PalmWatch	2026.03.06
Colgate	2024	F	Y	Y	Colgate (2024)	2026.03.06
Danone	2020	H2	Y	Y	Danone (2020)	2026.05.10
Danone	2024	H1	N	Y	Danone (2024)	2026.05.10
Ferrero	2020	H1	Y	Y	Ferrero (2020, 2023)	2026.03.06
Ferrero	2020	H2	Y	Y	Ferrero (2020, 2023)	2026.03.06
Ferrero	2023	H1	Y	Y	Ferrero (2020, 2023)	2026.03.06
Ferrero	2023	H2	Y	Y	Ferrero (2020, 2023)	2026.03.06
Hershey	2021	H1	Y	Y	Hershey (2021a)	2026.03.06
Hershey	2021	H2	Y	Y	Hershey (2021b)	2026.03.06
Hershey	2024	H1	Y	Y	Hershey (2024a)	2026.03.06
Hershey	2024	H2	Y	Y	Hershey (2024b)	2026.03.06
Kao	2021	F	Y	Y	Kao (2021)	2026.04.20
Kao	2024	H1	Y	Y	Kao (2024a)	2026.04.20
Kao	2024	H2	Y	Y	Kao (2024b)	2026.04.20
L'Oréal	2021	F	N	Y	PalmWatch	2026.03.06
L'Oréal	2024	F	N	Y	RSPO	2026.03.06
Lion	2021	F	Y	Y	Lion (2021)	2026.03.07
Lion	2024	H1	Y	Y	RSPO	2026.03.07
Lion	2024	H2	Y	Y	RSPO	2026.03.07
Mars	2020	S	N	N	PalmWatch	2026.03.07
Mars	2024	H1	Y	N	Mars (2024)	2026.03.07
Meiji	2021	H2	N	Y	RSPO	2026.04.27
Meiji	2024	H2	N	Y	RSPO	2026.04.27
Mondelez	2021	F	Y	Y	Mondelez (2021)	2026.05.10
Mondelez	2024	F	Y	Y	PalmWatch	2026.05.10

(Continued.)

Company	Year	Period	ID	GPS	Source	Last accessed
Nestlé	2020	S	Y	N	PalmWatch	2026.03.06
Nestlé	2023	S	Y	N	RSPO	2026.04.20
Nouryon	2020	H2	Y	Y	RSPO	2026.04.20
Nouryon	2023	H2	N	Y	RSPO	2026.04.20
P&G	2021	F	Y	Y	PalmWatch	2026.03.06
P&G	2024	H1	Y	Y	P&G (2024a)	2026.03.06
P&G	2024	H2	Y	Y	P&G (2024b)	2026.03.06
PZC	2020	S	Y	Y	PZ Cussons (2020)	2026.03.06
PZC	2024	F	Y	Y	PZ Cussons (2024)	2026.03.06
PepsiCo	2020	F	Y	Y	PalmWatch	2026.03.06
PepsiCo	2024	F	Y	Y	PepsiCo (2024)	2026.03.06
RFC	2020	H1	Y	Y	PalmWatch	2026.04.22
RFC	2020	H2	Y	Y	PalmWatch	2026.04.22
RFC	2024	F	Y	Y	RFC (2024)	2026.04.22
Reckitt	2020	F	Y	Y	PalmWatch	2026.03.07
Reckitt	2024	F	Y	Y	Reckitt (2024)	2026.03.07
Unilever	2020	F	Y	Y	PalmWatch	2026.03.06
Unilever	2024	F	Y	Y	Unilever (2024)	2026.02.28

Notes. Period: F = full year; H1 and H2 indicate the first and second half of the year, respectively; S indicates a snapshot at a specific time point (Mars, May 2020; PZC, December 2020; Nestlé, July 2020 and December 2023). ID and GPS indicate whether the list includes Universal Mill List identifiers (UML IDs) and geographic coordinates, respectively (Y/N). Source indicates the data source of each mill list. Mill lists correspond to the following reporting dates where applicable. URLs for all data sources are provided below.

Source URLs.

PalmWatch: <https://www.palmwatch.inclusivedevelopment.net>

RSPO: <https://rspo.org>

Bimbo (2020): <https://grupobimbo-com-custom01-assets.s3.amazonaws.com/s3fs-public/Grupo-Bimbo-2020-Mill-List.pdf>

Bimbo (2024): <https://d2rwhogv2mrkk6.cloudfront.net/s3fs-public/2025-06/2025%20GB.%20Direct%20palm%20oil%20mill%20list%28FY2024%29.pdf>

Colgate (2024): https://www.colgatepalmolive.com/content/dam/cp-sites-aem/corporate/corporate/en_us/corp/locale-assets/pdf/colgate-palm-oil-implementation-plan-2024.pdf

Danone (2020): <https://web.archive.org/web/20230127050514/https://www.danone.com/content/dam/danone-corp/danone-com/about-us-impact/policies-and-commitments/en/2021/Palm-oil-Suppliers-Mills-list-update-H2-2020-Danone.pdf>

Danone (2024): <https://www.danone.com/content/dam/corp/global/danonecom/about-us-impact/policies-and-commitments/en/2024/palm-oil-suppliers-mill-and-plantation-list-h1-2024.pdf>

Ferrero (2020, 2023): <https://www.ferrero.com/int/en/people-planet/source-our-ingredients-sustainably/palm-oil>

Hershey (2021a): <https://www.thehersheycompany.com/content/dam/hershey-corporate/documents/responsible-sourcing/palm-oil-sourcing/The%20Hershey%20Company%27s%20Palm%20Oil%20Mill%20List.pdf>

Hershey (2021b): <https://www.thehersheycompany.com/content/dam/hershey-corporate/documents/responsible-sourcing/palm-oil-sourcing/Hershey%20-%20July%20to%20December%202021%20Palm%20Mill%20List.pdf>

Hershey (2024a): <https://www.thehersheycompany.com/content/dam/hershey-corporate/documents/responsible-sourcing/palm-oil-sourcing/Hershey%20-%20January%20to%20June%202024%20Palm%20Mill%20List.pdf>

Hershey (2024b): <https://www.thehersheycompany.com/content/dam/hershey-corporate/documents/responsible-sourcing/palm-oil-sourcing/Hershey%20-%20July%20to%20Dec%202024%20Palm%20Mill%20List.pdf>

Kao (2021): <https://chainreactionresearch.com/files/content/dam/sites/kao/www-kao-com/global/en/sustainability/pdf/progress-2020-001.pdf>

Kao (2024a): <https://www.kao.com/content/dam/sites/kao/www-kao-com/global/en/sustainability/pdf/progress-2024-001.pdf>

Kao (2024b): <https://www.kao.com/content/dam/sites/kao/www-kao-com/global/en/sustainability/pdf/progress-2024-002.pdf>

Lion (2021): <https://www.lion.co.jp/ja/sustainability/businesscustom/pdf/mill-list-2021.pdf>

Nestlé (2023): <https://www.nestle.com/sites/default/files/2019-08/supply-chain-disclosure-palm-oil.pdf>

Mars (2024): <https://www.mars.com/sites/g/files/dfsbufz106/files/2025-07/Mars%20Global%20Palm%20Oil%20Mill%20List%20H1%202024.pdf>

Mondelez (2024): <https://www.mondelezinternational.com/assets/Snacking-Made-Right/Our-Positions/Palm-Oil/MDLZ-Palm-Oil-Mill-List.pdf>

P&G (2024a): https://assets.ctfassets.net/5gvshcnjyfm0/1Fvo9aTds7q2blscwibi7/fc8085a5e0ce73869fa6fec58f861560/PG-Palm-Oils-Mill-List-FINAL_JUL_2024_To_Publish_FPG.pdf

P&G (2024b): https://s204.q4cdn.com/332108499/files/doc_downloads/esg/pg-palm-oils-mill-list.pdf

PepsiCo (2024): <https://www.pepsico.com/docs/pepsico-5v9wci20/media/Files/esg-topics/2024-global-palm-oil-mill-list.pdf>

PZC (2020): <https://www.pzcussons.com/wp-content/uploads/2021/10/PZC-Palm-Oil-Mill-List-July-2021.pdf>

PZC (2024): <https://www.pzcussons.com/wp-content/uploads/2023/09/PZC-Palm-Oil-Supplier-Mill-List-July-2023.pdf>

Reckitt (2024): <https://www.reckitt.com/media/zzxd3x1u/2024-fb-sn-mill-list.pdf>

RFC (2024): <https://www.frieslandcampina.com/uploads/2025/07/Traceability-Palm-PKO-Mill-List-FrieslandCampina-FY-2024-Update-Q2-2025.pdf>

Unilever (2024): <https://www.unilever.com/files/unilever-palm-oil-mill-list-2024.pdf>

Supplementary Table 12: Summary of mill records by company and year.

Company	Year	Total	ID	Name	GPS	Excl	Mills (all)	Mills (shared)
Bimbo	2020	11547	11049	255	148	95	1903	1753
Bimbo	2024	1477	1471	0	1	5	1471	1470
Blommer	2021	3192	0	1987	1173	32	971	965
Blommer	2024	2152	0	2137	15	0	968	922
Colgate	2020	4162	4046	59	38	19	1273	1261
Colgate	2024	1286	1269	4	0	13	664	627
Danone	2020	1100	1078	11	0	11	1089	1082
Danone	2024	319	0	283	36	0	174	173
Ferrero	2020	2005	1955	32	8	10	771	767
Ferrero	2023	708	706	0	0	2	312	308
Hershey	2021	2246	2191	30	22	3	1272	1264
Hershey	2024	1950	1944	3	3	0	1124	1051
Kao	2021	919	801	33	42	43	842	839
Kao	2024	2758	2742	2	2	12	1373	1324
L'Oréal	2021	946	0	441	486	19	921	920
L'Oréal	2024	1089	0	1078	9	2	1087	1054
Lion	2021	1348	1261	17	19	51	1280	1277
Lion	2024	1463	1440	4	3	16	1441	1378
Mars	2020	1249	0	976	0	273	974	964
Mars	2024	181	181	0	0	0	181	179
Meiji	2021	1248	0	1186	38	24	1212	1208
Meiji	2024	1777	0	1737	17	23	1746	1643
Mondelez	2021	1620	1565	3	35	17	1603	1589
Mondelez	2024	1595	1584	1	2	8	1573	1469
Nestlé	2020	15703	15527	45	0	131	1617	1577
Nestlé	2023	15600	15582	0	0	18	1716	1669
Nouryon	2020	1874	0	543	1285	46	1211	1198
Nouryon	2023	304	300	0	4	0	304	295
P&G	2021	1250	1225	16	8	1	1248	1245
P&G	2024	2571	2569	0	0	2	1475	1393
PZC	2020	1734	1600	53	43	38	1665	1608

(Continued.)

Company	Year	Total	ID	Name	GPS	Excl	Mills (all)	Mills (shared)
PZC	2024	1824	1795	11	14	4	1819	1656
PepsiCo	2020	1710	0	916	770	24	1664	1621
PepsiCo	2024	1859	1808	5	29	17	1822	1683
RFC	2020	6843	4268	138	2216	221	1368	1346
RFC	2024	1884	1864	7	7	6	902	840
Reckitt	2020	4813	4636	90	51	36	1414	1401
Reckitt	2024	1708	1693	7	5	3	1704	1580
Unilever	2020	1613	1602	0	0	11	1602	1566
Unilever	2024	417	417	0	0	0	417	409

Notes. Columns report the total number of records (Total); records with valid Universal Mill List identifiers, or UML IDs (ID); and records without a UML ID for which an ID was assigned by matching mill names (Name) or GPS coordinates (GPS) against the Universal Mill List. Records were excluded if their reported IDs were not found in the Universal Mill List or if no UML ID could be assigned (Excl). Mills (all) and Mills (shared) report the numbers of unique mills after duplicate records were removed. Mills (shared) includes only mills appearing in both study periods (P1: 2020–2021 and P2: 2023–2024). See Supplementary Note 2 for methodological details.

Supplementary Table 13: Correlation matrix among continuous predictors in the retention model.

Term	DF (log ha, 20 km)	Degree (log)	STAR (20 km)
DF (log ha, 20 km)	1.000	0.164	0.152
Degree (log)	0.164	1.000	0.032
STAR (20 km)	0.152	0.032	1.000

Notes. DF (log ha, 20 km) denotes log-transformed deforestation area (ha) within a 20-km buffer. Degree (log) denotes log-transformed mill degree in period 2020–2021. STAR (20 km) denotes the proportion of high species extinction risk area within a 20-km buffer.

Supplementary Table 14: Variance inflation factors for fixed effects in the retention model.

Term	GVIF	Df	$GVIF^{1/(2 \cdot Df)}$
Company	1.128	19	1.003
Degree (log)	1.073	1	1.036
STAR (20 km)	1.025	1	1.013
DF (log ha, 20 km)	1.025	1	1.012
Certification	1.073	3	1.012

Notes. DF (log ha, 20 km), Degree (log), STAR (20 km) are defined as in Supplementary Table 3. Company and certification are included as categorical variables. GVIF, generalized variance inflation factor; Df, degrees of freedom.

Supplementary Table 15: Correlation matrix among continuous predictors in the addition model.

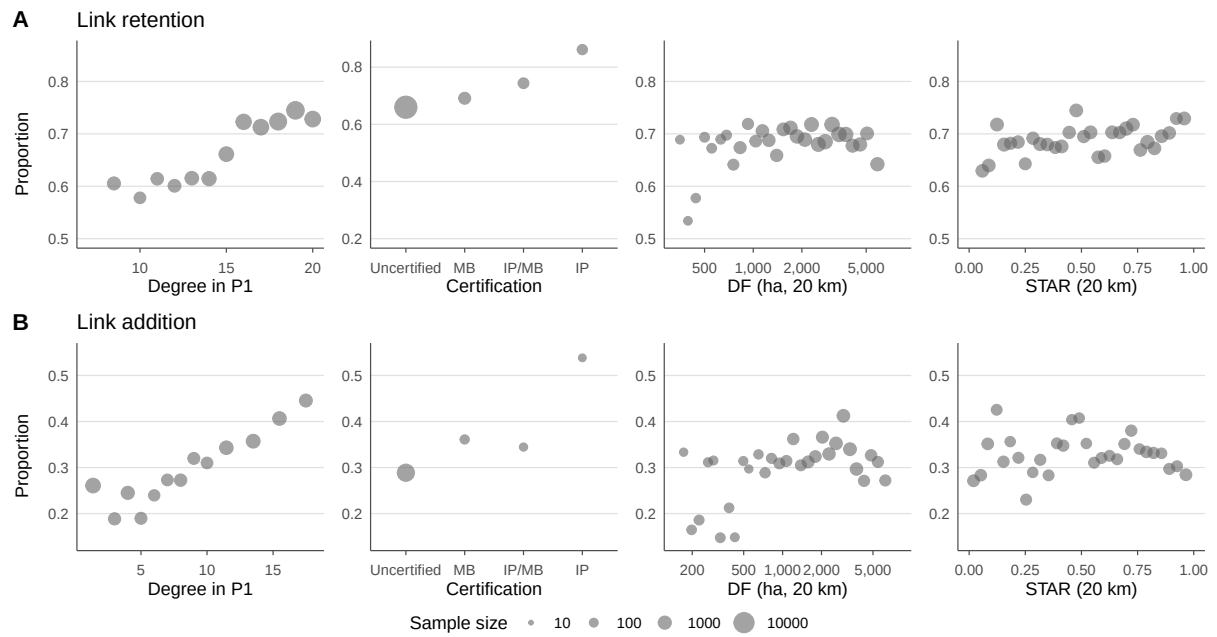
Term	DF (log ha, 20 km)	Degree (log)	STAR (20 km)
DF (log ha, 20 km)	1.000	0.090	0.284
Degree (log)	0.090	1.000	0.116
STAR (20 km)	0.284	0.116	1.000

Notes. DF (log ha, 20 km) denotes log-transformed deforestation area (ha) within a 20-km buffer. Degree (log) denotes log-transformed mill degree in period 2020–2021. STAR (20 km) denotes the proportion of high species extinction risk area within a 20-km buffer.

Supplementary Table 16: Variance inflation factors for fixed effects in the addition model.

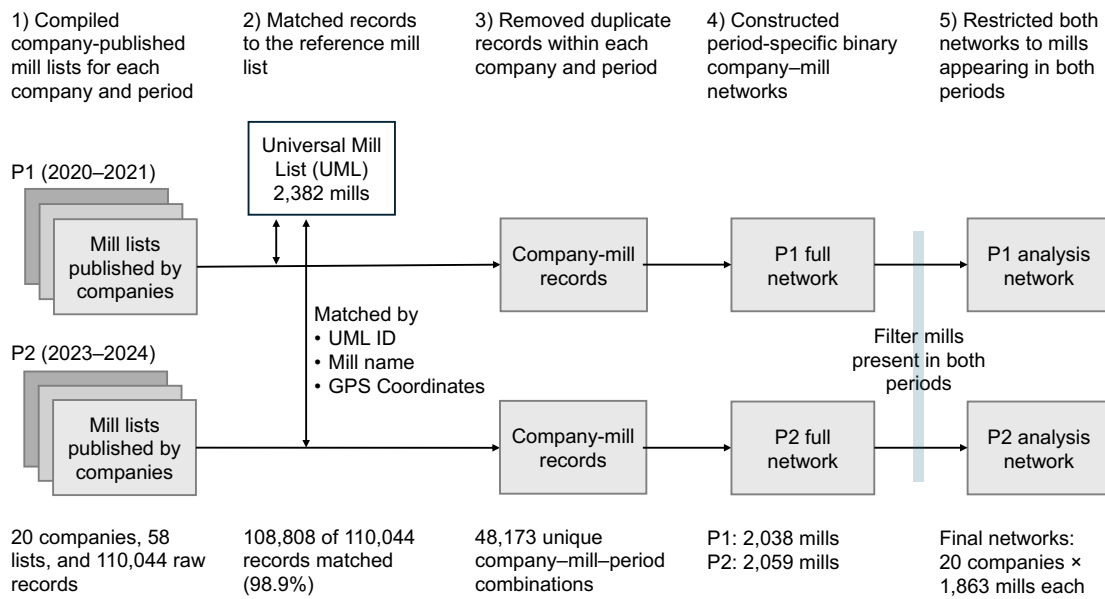
Term	GVIF	Df	$GVIF^{1/(2 \cdot Df)}$
Company	1.128	19	1.003
Degree (log)	1.127	1	1.061
STAR (20 km)	1.049	1	1.024
DF (log ha, 20 km)	1.049	1	1.024
Certification	1.050	3	1.008

Notes. DF (log ha, 20 km), Degree (log), STAR (20 km) are defined as in Supplementary Table 4. Company and certification are included as categorical variables. GVIF, generalized variance inflation factor; Df, degrees of freedom.



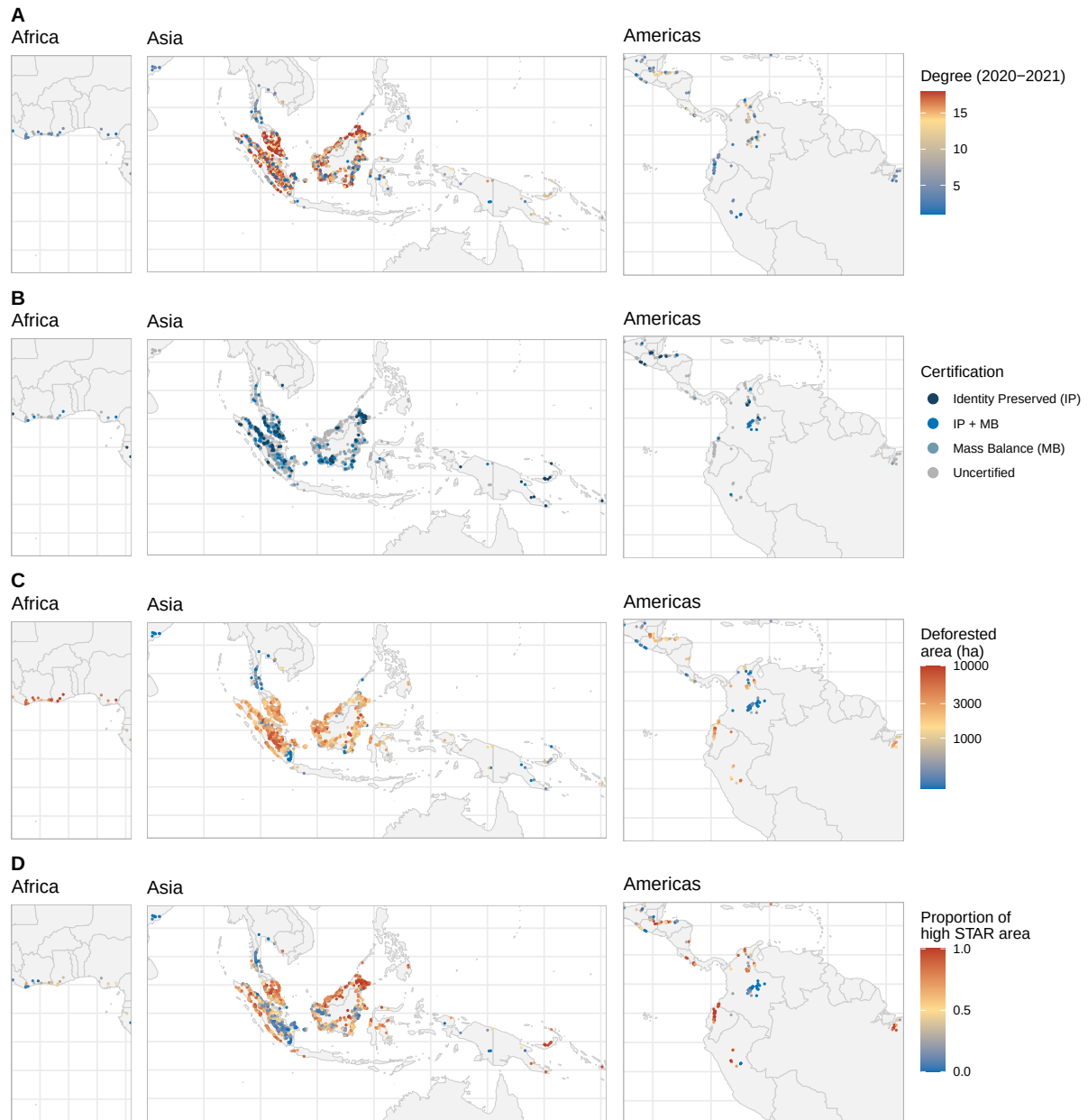
Supplementary Figure 1: Unadjusted empirical relationships between the focal variables and link retention and addition.

Points show binned observed proportions of retained or newly added company–mill links. Observations were grouped into adaptive bins containing at least 10 observations, and point size indicates the number of observations in each bin. These proportions represent unadjusted relationships and are shown only within the 5th–95th percentile range of each focal continuous variable. Results should be interpreted alongside the corresponding model-based predictions in Figure 2.



Supplementary Figure 2: Workflow used to construct the company-mill networks for the two study periods.

Company-published mill lists were compiled for each company in P1 (2020–2021) and P2 (2023–2024). Records were matched to the Universal Mill List (UML; 2,382 mills) using UML ID, mill name, and GPS coordinates. Of 110,044 raw records from 58 lists covering 20 companies, 108,808 records (98.9%) were successfully matched. After duplicate records were removed within each company and period, 48,173 unique company-mill-period combinations remained. These were used to construct binary bipartite company-mill networks for each period, comprising 2,038 mills in P1 and 2,059 mills in P2. For comparative analyses, both networks were then restricted to the 1,863 mills that appeared in at least one company list in both periods, resulting in final analysis networks of 20 companies × 1,863 mills for each period.



Supplementary Figure 3: Distribution of mills included in the GLMM models.

Point colors indicate the degree in the first period (2020–2021) (A), certification status (B), deforestation area (ha) (C), and the proportion of high STAR area (D).