Supplementary information for “Welfare gradients in global animal-source food consumption reveal that aquatic foods are critical for poor households”

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Christopher D. Golden

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1. Maps

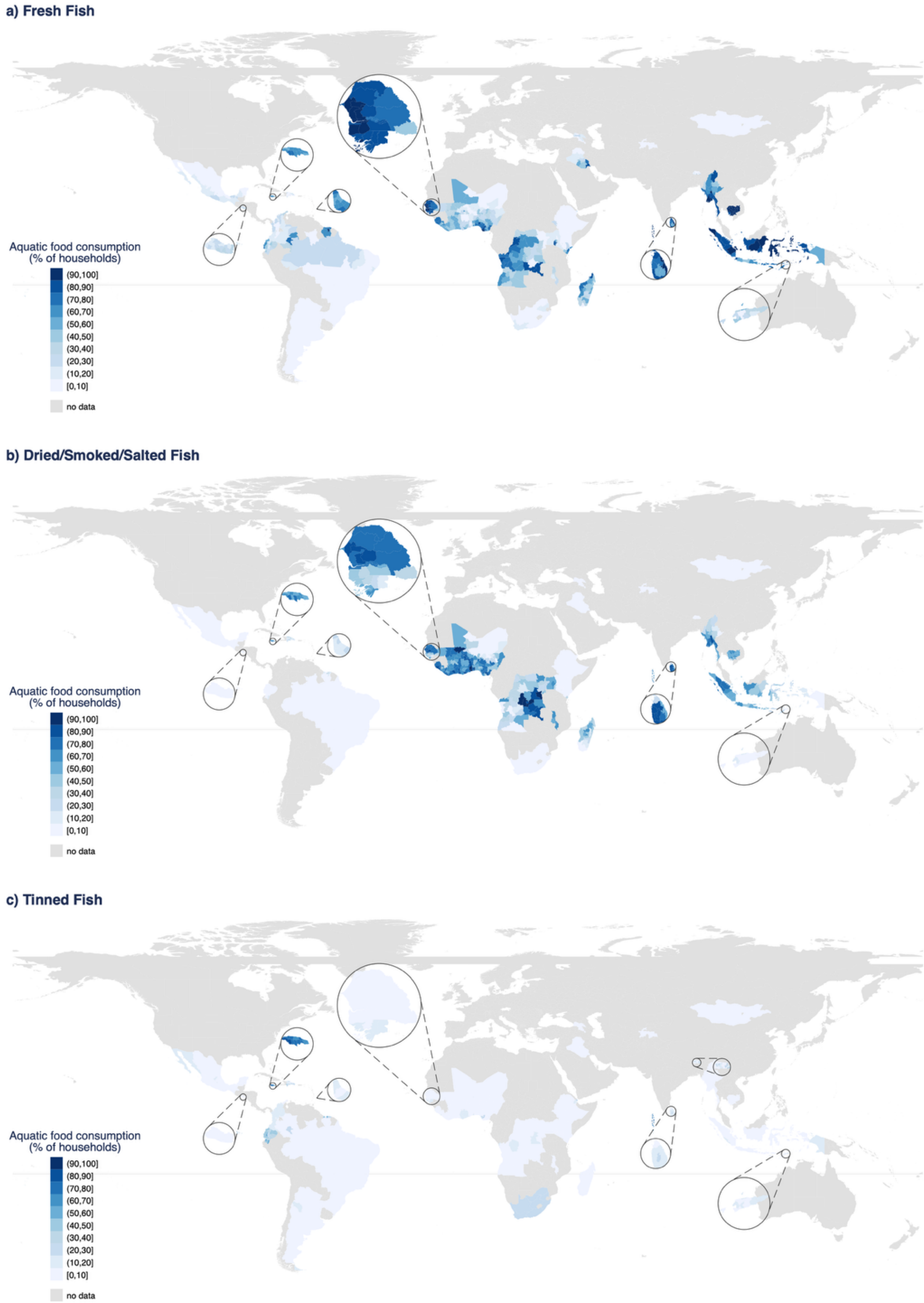


Fig. S1 | Fish consumption by processing type in 49 countries. Shades of blue indicate the proportion of households that consumed each food group within the past week at administrative 1 level in 49 countries. Household weights adjusted for sampling design are applied where applicable. Panel a) indicates fresh fish, panel b) dried, smoked, and salted fish, panel c) tinned fish.

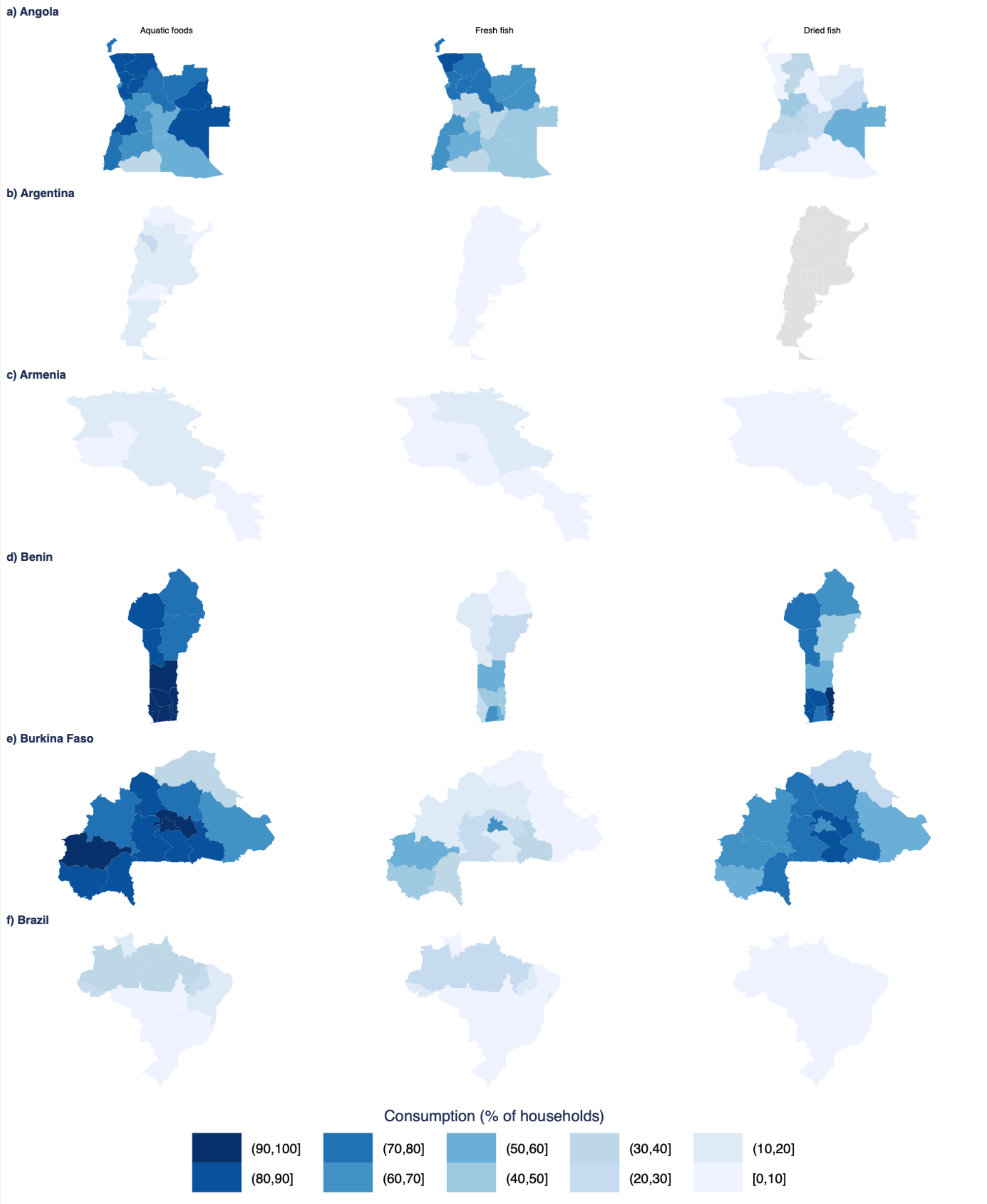


Fig. S2 (panel a-f) | Subnational variation in aquatic food consumption by country. Maps show the weighted share of households in each ADM1 region reporting consumption of aquatic foods, fresh fish, and dried fish. Gray ADM1 regions indicate regions without available data. Panel letters continue across pages. Countries are ordered alphabetically. Shapefiles are from GADM, except for Madagascar, Uganda, Liberia, Maldives, Sri Lanka, and Myanmar, which use Humanitarian Data Exchange boundaries, and Malawi, Gambia, and Namibia, which use AidData boundaries to better align regions with the survey year. Tonga was excluded because its dispersed islands are not visible at the common map scale.

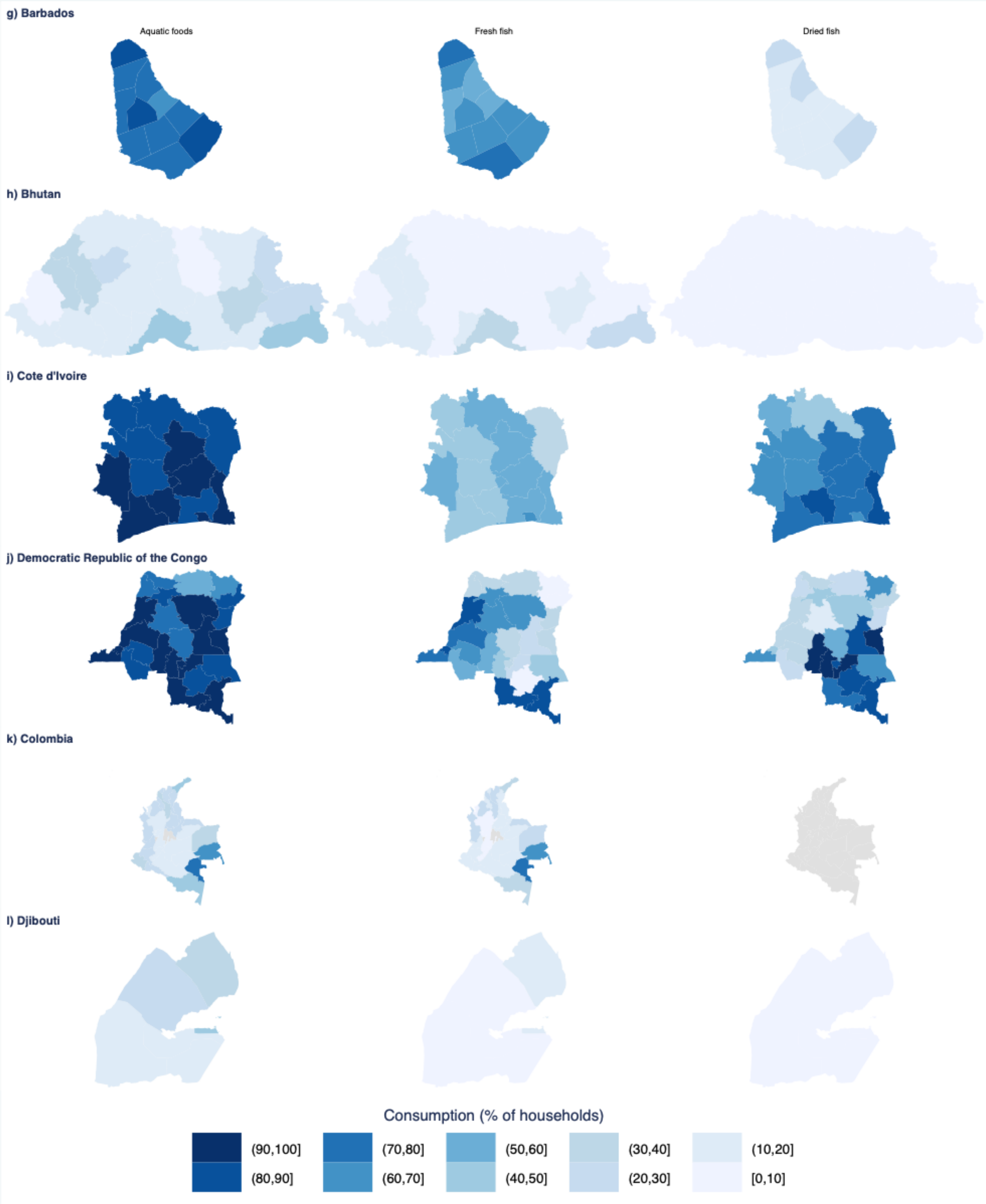


Fig. S2 (panel g-l) | Subnational variation in aquatic food consumption by country. Maps show the weighted share of households in each ADM1 region reporting consumption of aquatic foods, fresh fish, and dried fish. Gray ADM1 regions indicate regions without available data. Panel letters continue across pages. Countries are ordered alphabetically. Shapefiles are from GADM, except for Madagascar, Uganda, Liberia, Maldives, Sri Lanka, and Myanmar, which use Humanitarian Data Exchange boundaries, and Malawi, Gambia, and Namibia, which use AidData boundaries to better align regions with the survey year.

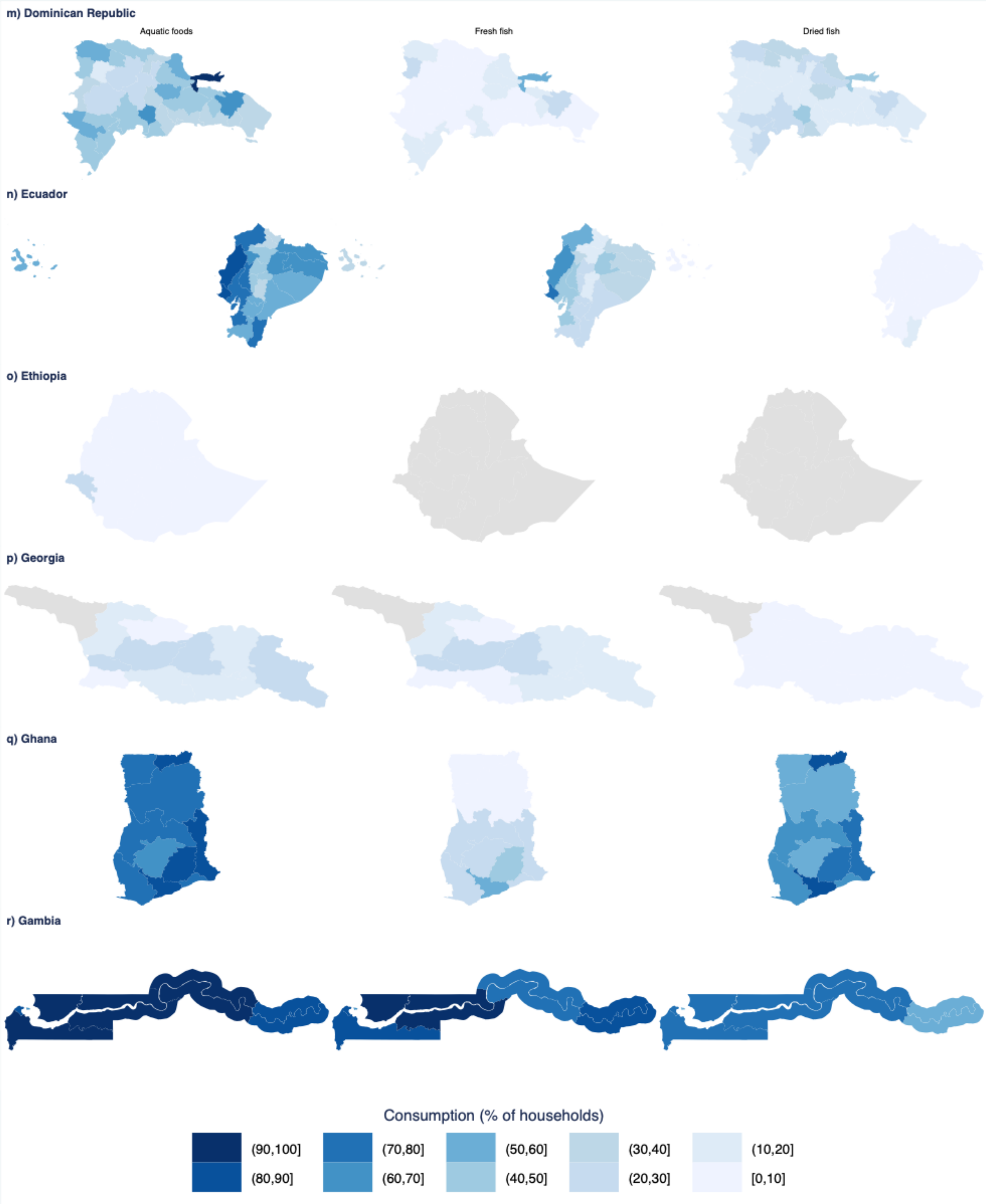


Fig. S2 (panel m-r) | Subnational variation in aquatic food consumption by country. Maps show the weighted share of households in each ADM1 region reporting consumption of aquatic foods, fresh fish, and dried fish. Gray ADM1 regions indicate regions without available data. Panel letters continue across pages. Countries are ordered alphabetically. Shapefiles are from GADM, except for Madagascar, Uganda, Liberia, Maldives, Sri Lanka, and Myanmar, which use Humanitarian Data Exchange boundaries, and Malawi, Gambia, and Namibia, which use AidData boundaries to better align regions with the survey year.

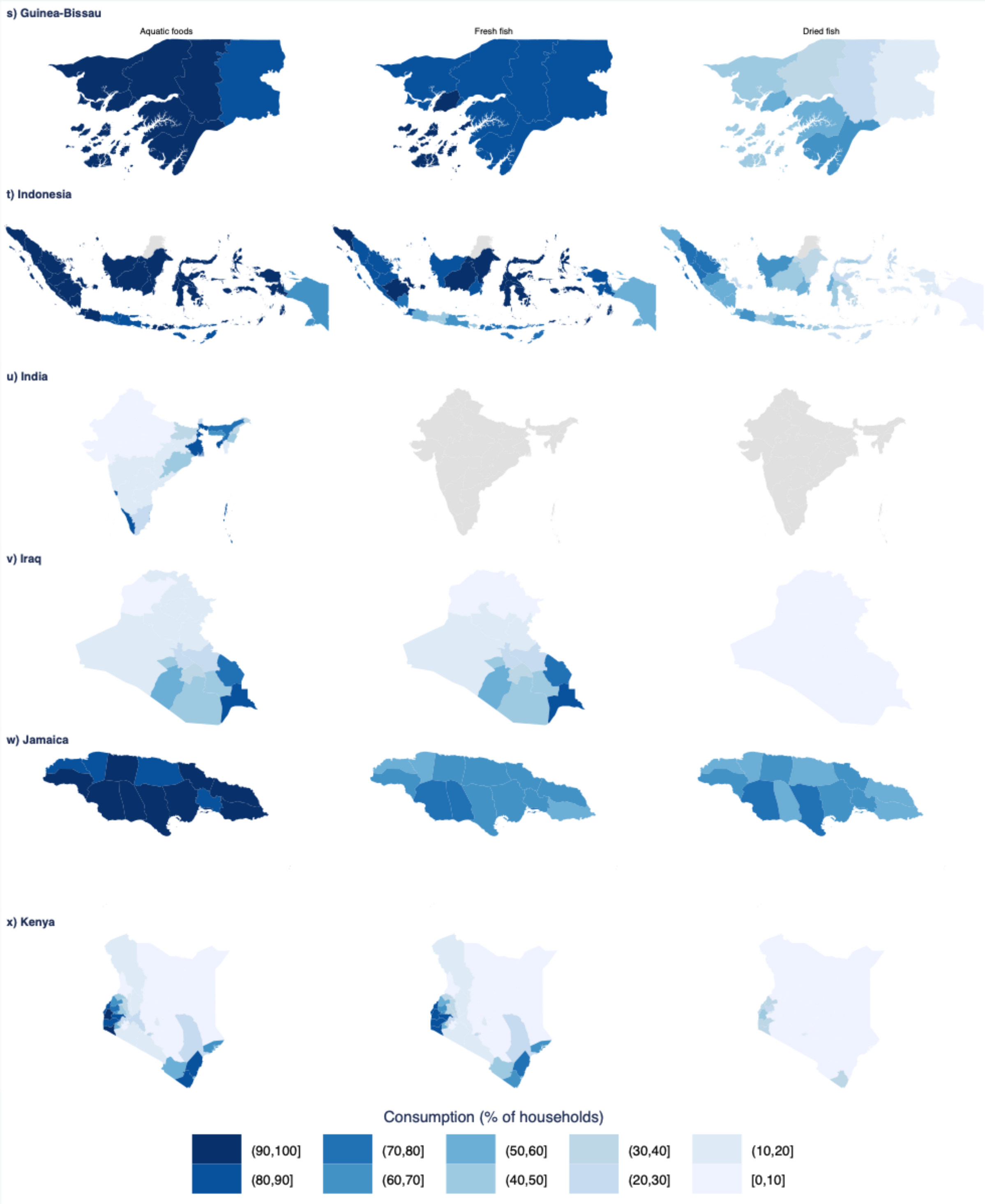


Fig. S2 (panel s-x) | Subnational variation in aquatic food consumption by country. Maps show the weighted share of households in each ADM1 region reporting consumption of aquatic foods, fresh fish, and dried fish. Gray ADM1 regions indicate regions without available data. Panel letters continue across pages. Countries are ordered alphabetically. Shapefiles are from GADM, except for Madagascar, Uganda, Liberia, Maldives, Sri Lanka, and Myanmar, which use Humanitarian Data Exchange boundaries, and Malawi, Gambia, and Namibia, which use AidData boundaries to better align regions with the survey year.

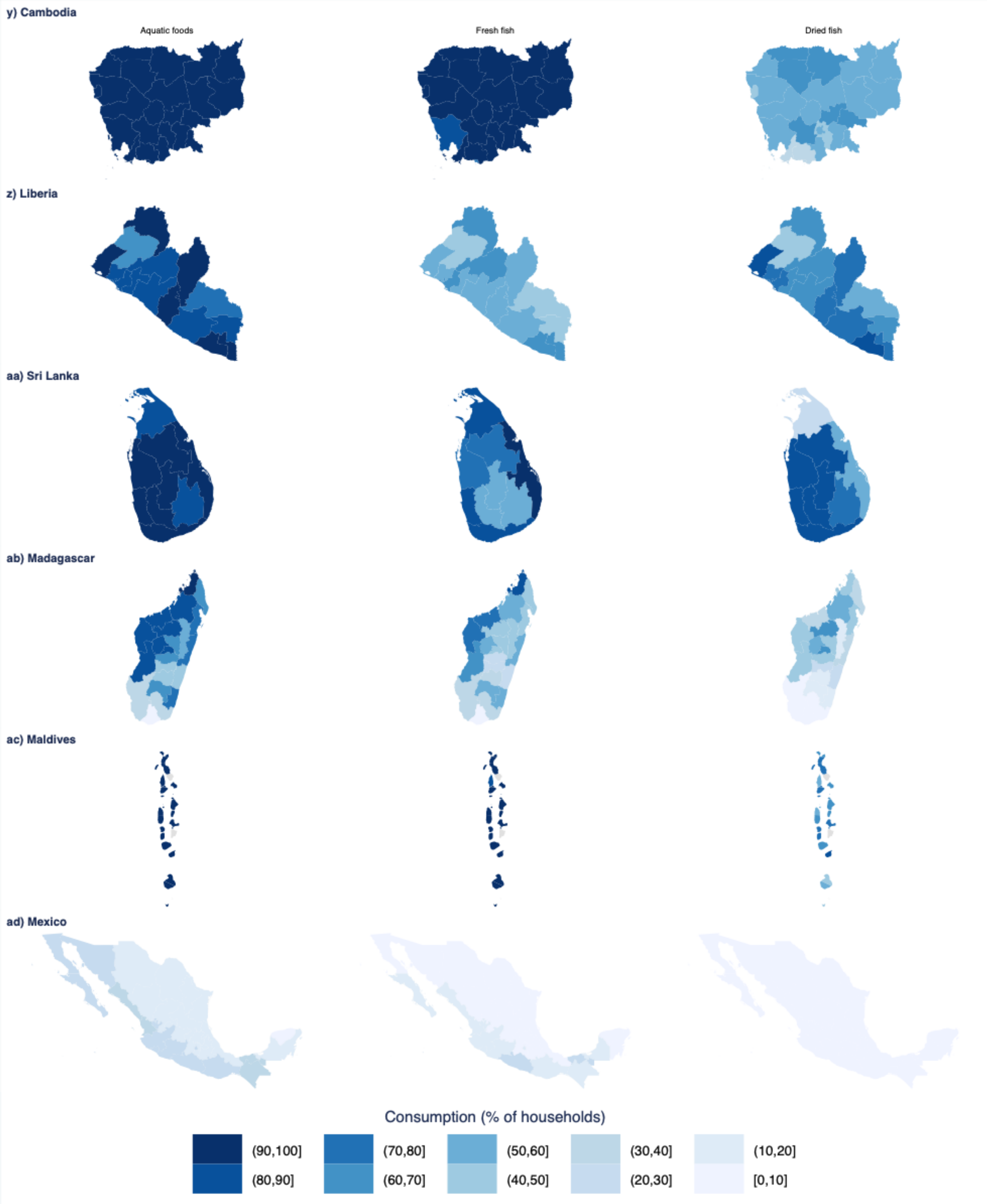


Fig. S2 (panel y-ad) | Subnational variation in aquatic food consumption by country. Maps show the weighted share of households in each ADM1 region reporting consumption of aquatic foods, fresh fish, and dried fish. Gray ADM1 regions indicate regions without available data. Panel letters continue across pages. Countries are ordered alphabetically. Shapefiles are from GADM, except for Madagascar, Uganda, Liberia, Maldives, Sri Lanka, and Myanmar, which use Humanitarian Data Exchange boundaries, and Malawi, Gambia, and Namibia, which use AidData boundaries to better align regions with the survey year.

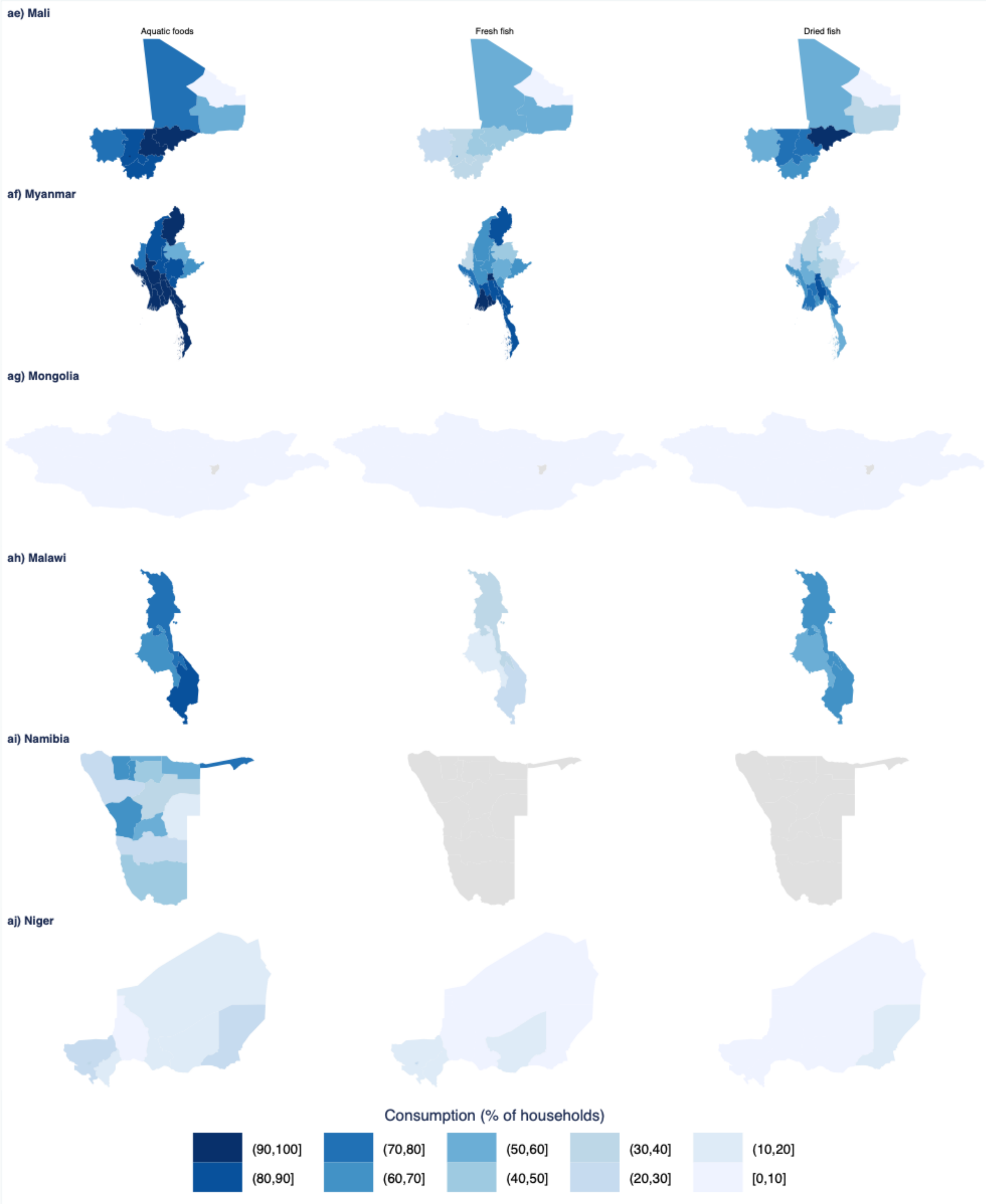


Fig. S2 (panel ae-aj) | Subnational variation in aquatic food consumption by country. Maps show the weighted share of households in each ADM1 region reporting consumption of aquatic foods, fresh fish, and dried fish. Gray ADM1 regions indicate regions without available data. Panel letters continue across pages. Countries are ordered alphabetically. Shapefiles are from GADM, except for Madagascar, Uganda, Liberia, Maldives, Sri Lanka, and Myanmar, which use Humanitarian Data Exchange boundaries, and Malawi, Gambia, and Namibia, which use AidData boundaries to better align regions with the survey year.

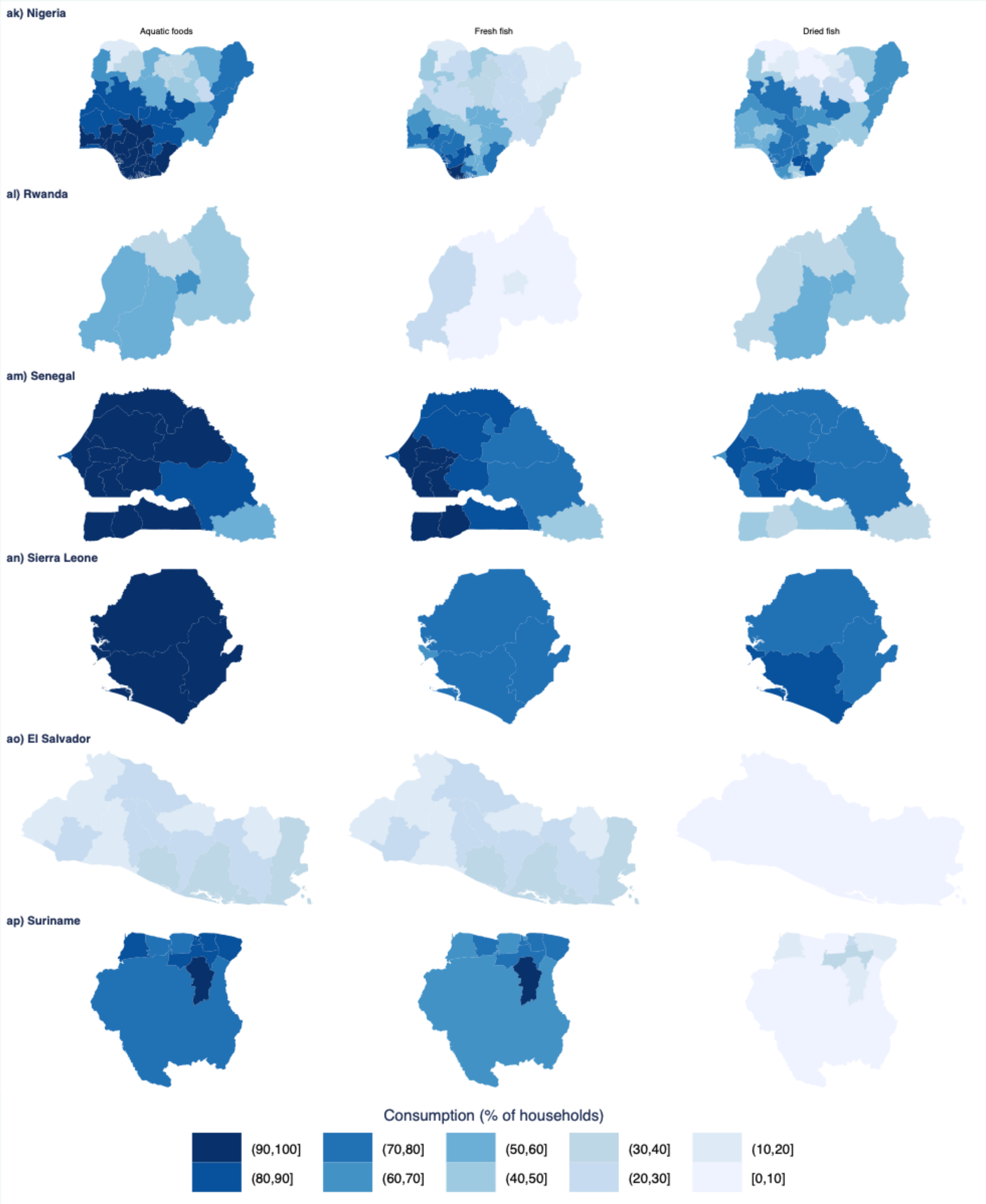


Fig. S2 (panel ak-ap) | Subnational variation in aquatic food consumption by country. Maps show the weighted share of households in each ADM1 region reporting consumption of aquatic foods, fresh fish, and dried fish. Gray ADM1 regions indicate regions without available data. Panel letters continue across pages. Countries are ordered alphabetically. Shapefiles are from GADM, except for Madagascar, Uganda, Liberia, Maldives, Sri Lanka, and Myanmar, which use Humanitarian Data Exchange boundaries, and Malawi, Gambia, and Namibia, which use AidData boundaries to better align regions with the survey year.

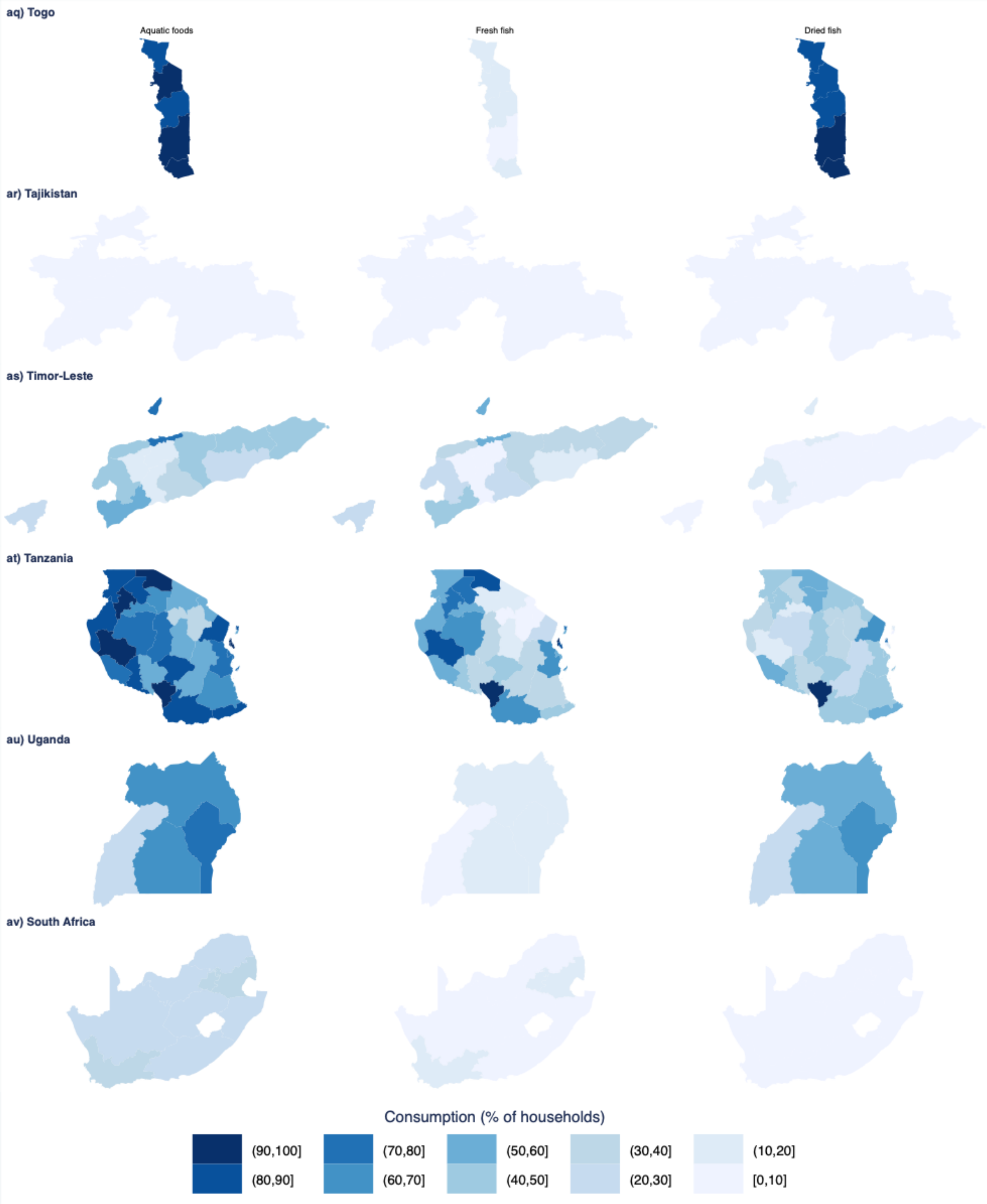


Fig. S2 (panel aq-av) | Subnational variation in aquatic food consumption by country. Maps show the weighted share of households in each ADM1 region reporting consumption of aquatic foods, fresh fish, and dried fish. Gray ADM1 regions indicate regions without available data. Panel letters continue across pages. Countries are ordered alphabetically. Shapefiles are from GADM, except for Madagascar, Uganda, Liberia, Maldives, Sri Lanka, and Myanmar, which use Humanitarian Data Exchange boundaries, and Malawi, Gambia, and Namibia, which use AidData boundaries to better align regions with the survey year.

2. Distance to water resources

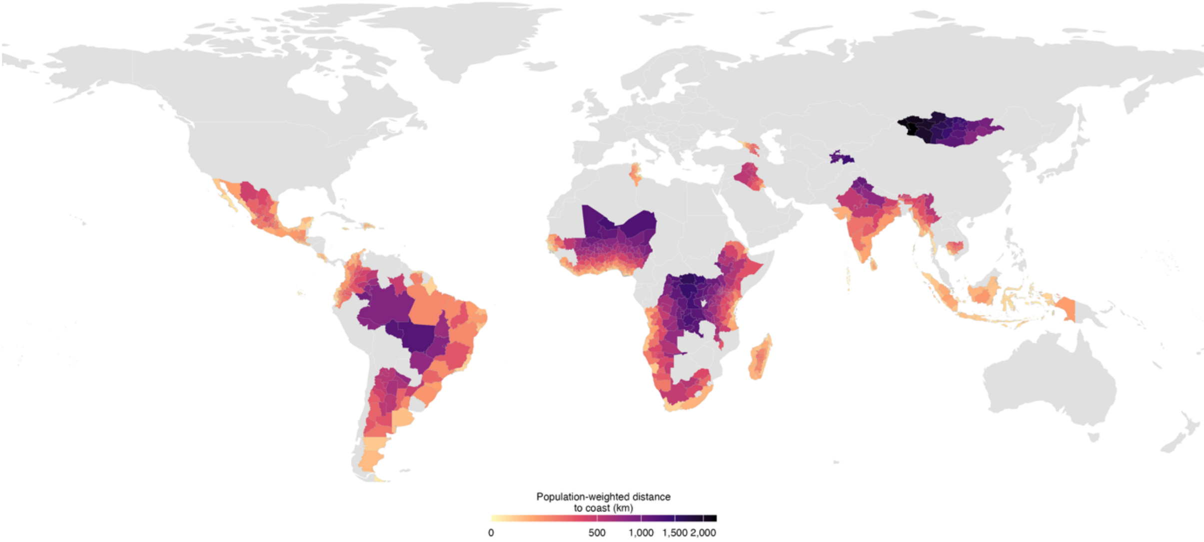
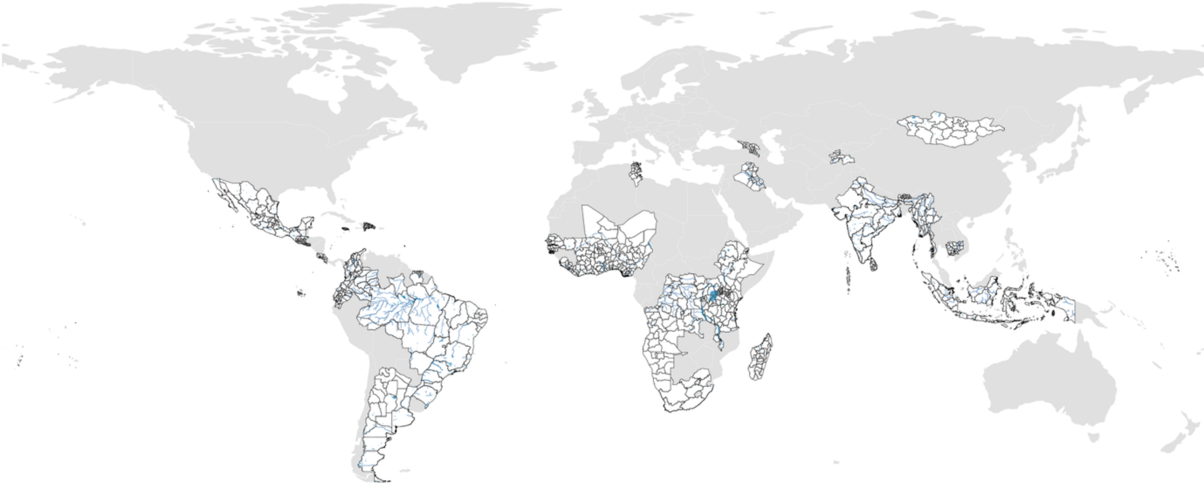


Fig. S3 | ADM1 distance to marine water. Map shows ADM1 population-weighted distance to the nearest coastline. Distances are calculated as the population-weighted mean straight-line distance from populated raster cells within each ADM1 region to the coastline. Gray countries are outside the mapped analytic sample. Coastlines are based on Natural Earth.

a) Qualifying major freshwater resources



b) Regional population-weighted distance to major freshwater resources

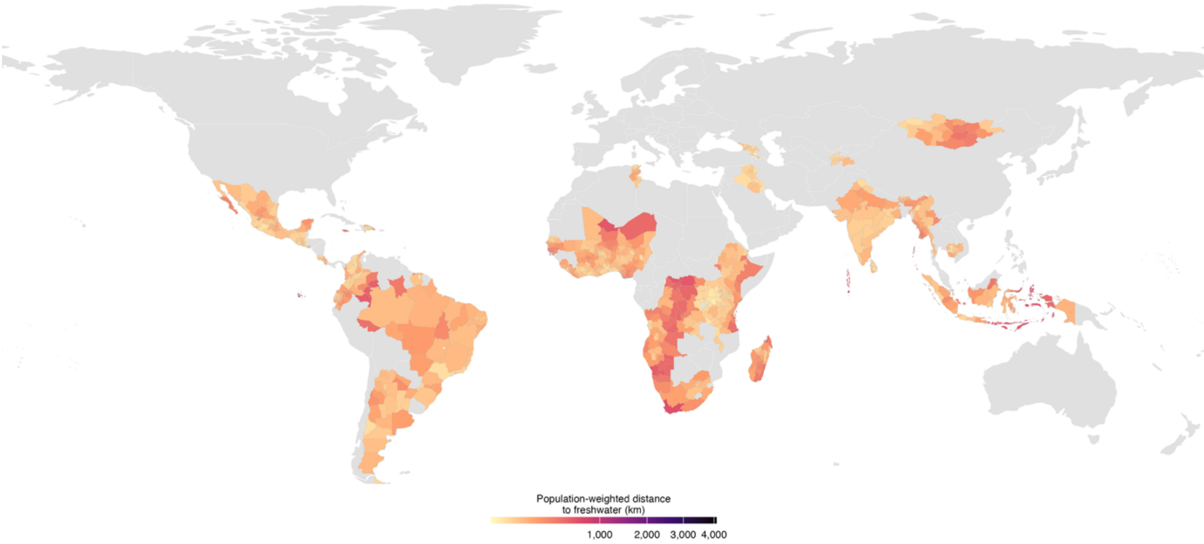


Fig. S4 | ADM1 exposure to major freshwater resources. Map (**a**) shows qualifying freshwater resources for sample countries. Freshwater resources combine HydroLAKES polygons restricted to large lakes/reservoirs and HydroRIVERS reaches with average discharge ≥500 m³/s (see 'Methods'). Map (**b**) shows ADM1 population-weighted distance to qualifying freshwater resources. Distances are calculated as the population-weighted mean straight-line distance from populated raster cells within each ADM1 region. Gray countries are outside the mapped analytic sample.

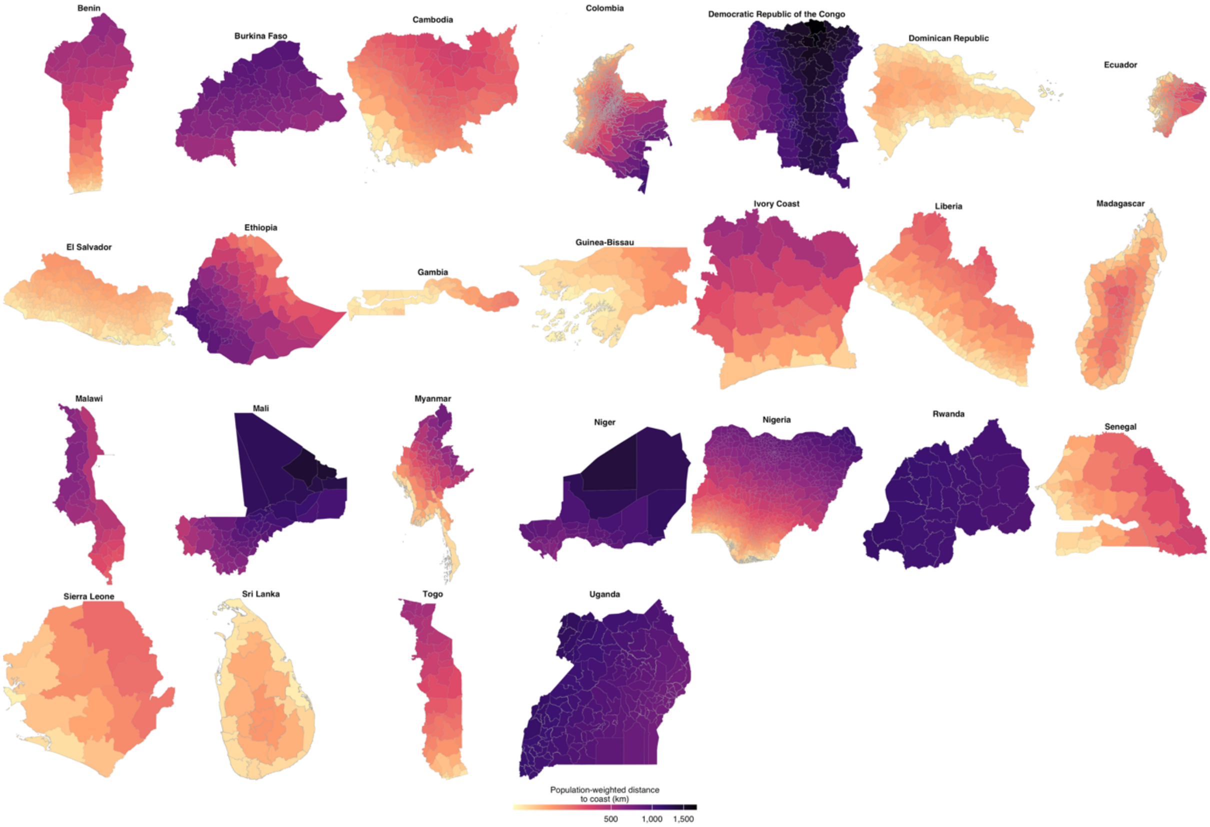


Fig. S5 | ADM2 distance to marine water. Maps show ADM2 population-weighted distance to the nearest coastline for countries with named ADM2 regions in the household data. Distances are calculated as the population-weighted mean straight-line distance from populated raster cells within each ADM2 region to the Natural Earth coastline.

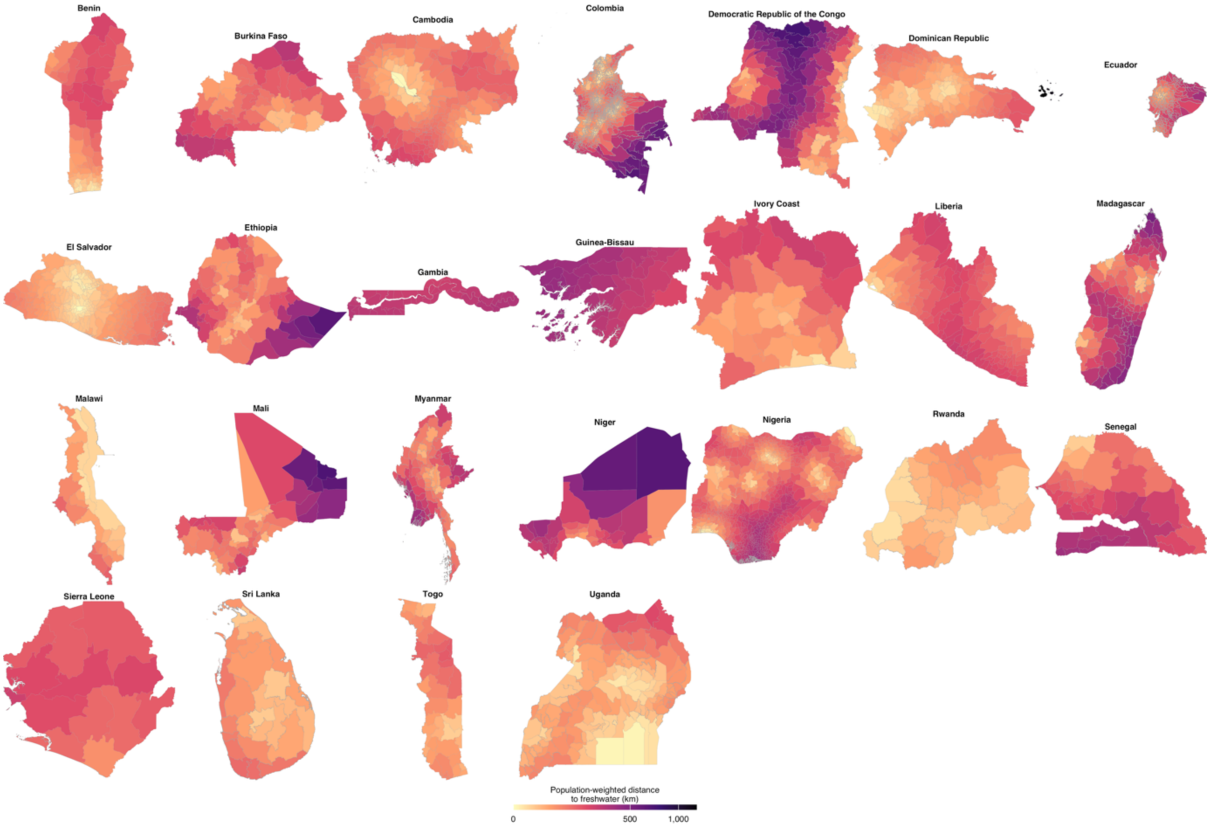


Fig. S6 | ADM2 exposure to major freshwater resources. Maps show ADM2 population-weighted distance to qualifying freshwater resources for countries with named ADM2 regions in the household data. Freshwater resources combine qualifying HydroLAKES lakes/reservoirs and HydroRIVERS river reaches. Distances are population-weighted across populated raster cells within each ADM2 region.

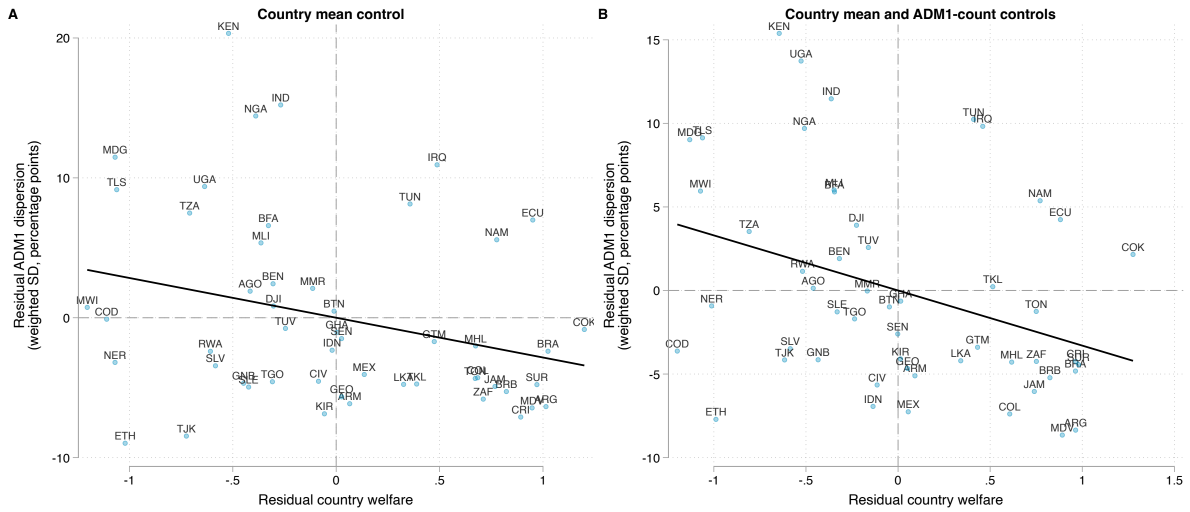


Fig. S7 | Spatial unevenness in aquatic food consumption is greater in poorer countries. Geographic unevenness is measured as the population-weighted standard deviation of ADM1-level aquatic food consumption prevalence within each country. Panel **A** shows the partial correlation between country welfare and geographic unevenness after controlling for national mean aquatic food consumption prevalence. Panel **B** repeats the analysis after additionally controlling for the log number of ADM1 regions, to account for differences in administrative partitioning across countries. Negative x-values indicate countries poorer than expected given the included controls.

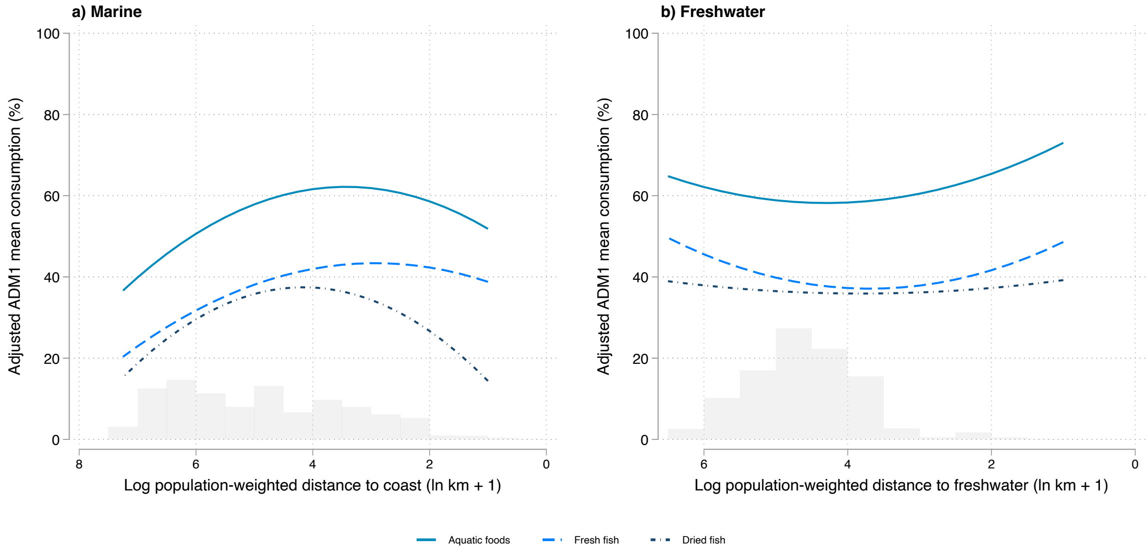


Fig. S8 | Adjusted consumption gradients by marine and freshwater exposure. Lines show adjusted ADM1-level associations between fish consumption and population-weighted distance to marine water and freshwater. Models use ADM1-level means, weight ADM1 observations by represented household population, include country fixed effects and ADM1-level controls including month, household size, urban residence, agricultural occupation, and log per-capita expenditure, and model both water-distance measures quadratically. Distance is measured as ln(km + 1), with x-axes reversed so proximity to water increases from left to right. Values of 1, 2, 3, 4, 5, 6, and 7 correspond to approximately 1.7, 6.4, 19, 54, 147, 402, and 1,096 km, respectively. Gray bars show weighted household exposure distributions.

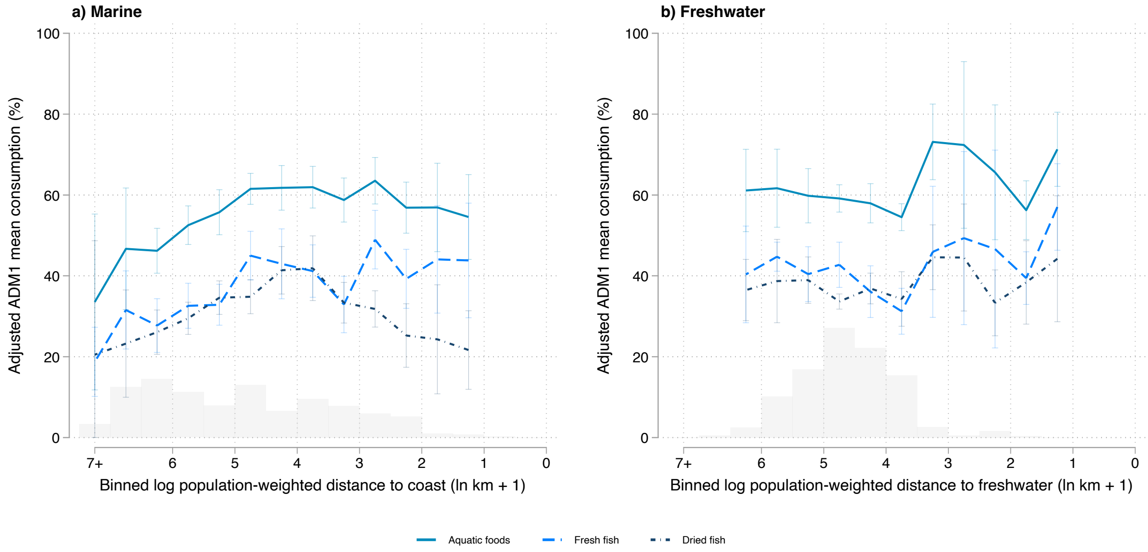


Fig. S9 | Binned adjusted consumption gradients by marine and freshwater exposure. Lines show adjusted ADM1-level mean consumption by binned population-weighted distance to marine water and freshwater. Bins are defined over log distance, ADM1 observations are weighted by represented household population, and vertical bars show confidence intervals for bin-level adjusted predictions. Values of 1, 2, 3, 4, 5, 6, and 7 correspond to approximately 1.7, 6.4, 19, 54, 147, 402, and 1,096 km, respectively. Gray histograms show the distribution of represented population across distance bins.

Fig. S10 | Country-specific marine proximity gradients in aquatic food consumption. Country panels show unadjusted ADM1-level local polynomial smooths of aquatic food, fresh-fish, and dried/smoked-fish consumption against population-weighted distance to the coast. Household outcomes are collapsed to ADM1 means using household population weights, and ADM1 observations are weighted by represented household population. Confidence bands are omitted for readability; gray histograms show within-country represented population shares across exposure values.

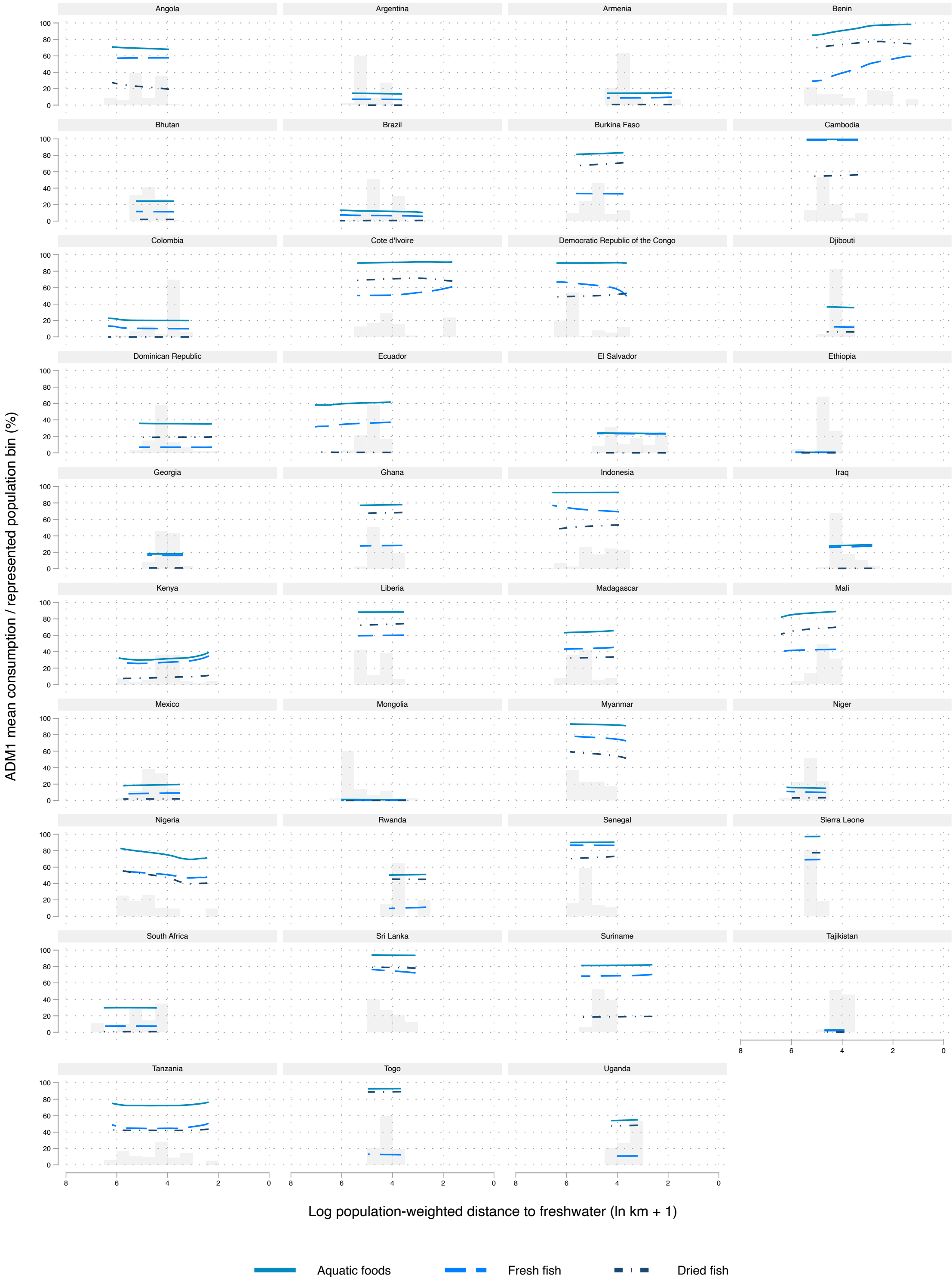


Fig. S11 | Country-specific freshwater exposure gradients in aquatic food consumption. Country panels show unadjusted ADM1-level local polynomial smooths of consumption against population-weighted distance to qualifying freshwater resources. Countries without qualifying freshwater exposure are excluded. Household outcomes are collapsed to ADM1 means using household population weights, and ADM1 observations are weighted by represented household population; gray histograms show within-country represented population shares.

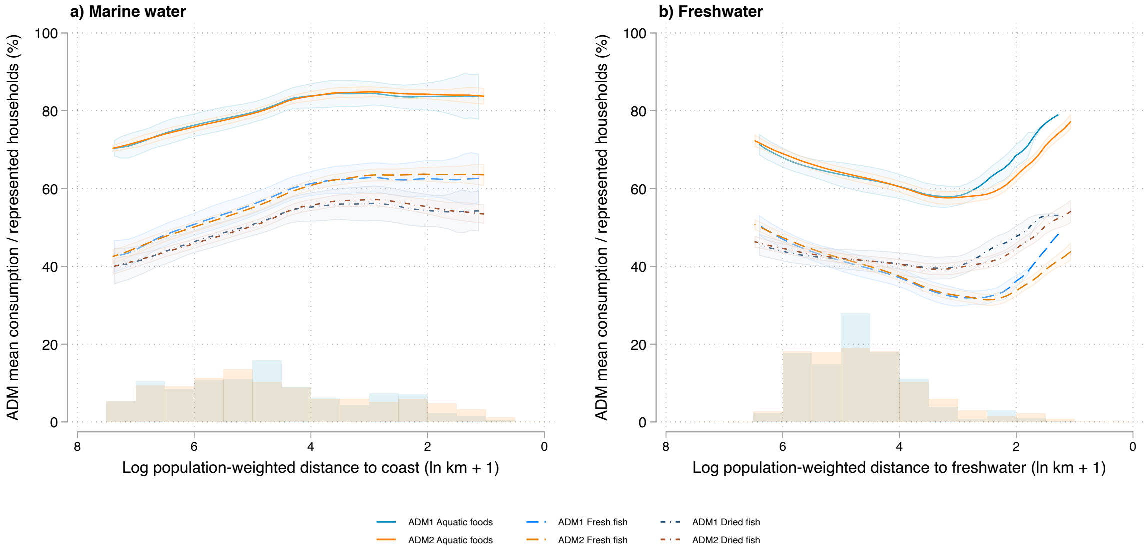


Fig. S12 | Sensitivity to ADM1 versus ADM2 exposure assignment. Lines show unadjusted local-polynomial associations between aquatic food consumption and population-weighted distance to marine water (**a**) and freshwater resources (**b**), comparing exposure assigned at the ADM1 and ADM2 levels. Household outcomes are collapsed separately to ADM1 and ADM2 regional means using the same ADM2-matched household sample, and regions are weighted by represented household population. Distances are measured as ln(km + 1), with x-axes reversed so proximity to water increases from left to right. Values of 1, 2, 3, 4, 5, 6, and 7 correspond to approximately 1.7, 6.4, 19, 54, 147, 402, and 1,096 km, respectively. Shaded bands indicate pointwise confidence intervals. Histograms show represented population shares by exposure bin.

Fig. S13 | Marine proximity gradients compared across ADM1 and ADM2 exposure assignments. Country panels compare unadjusted ADM1- and ADM2-level smooths for population-weighted distance to the coast. Household outcomes are collapsed separately to ADM1 and ADM2 region means using household population weights, and regions are weighted by represented household population. Gray and orange histograms show the distribution of represented population across exposure values for ADM1 and ADM2, respectively.

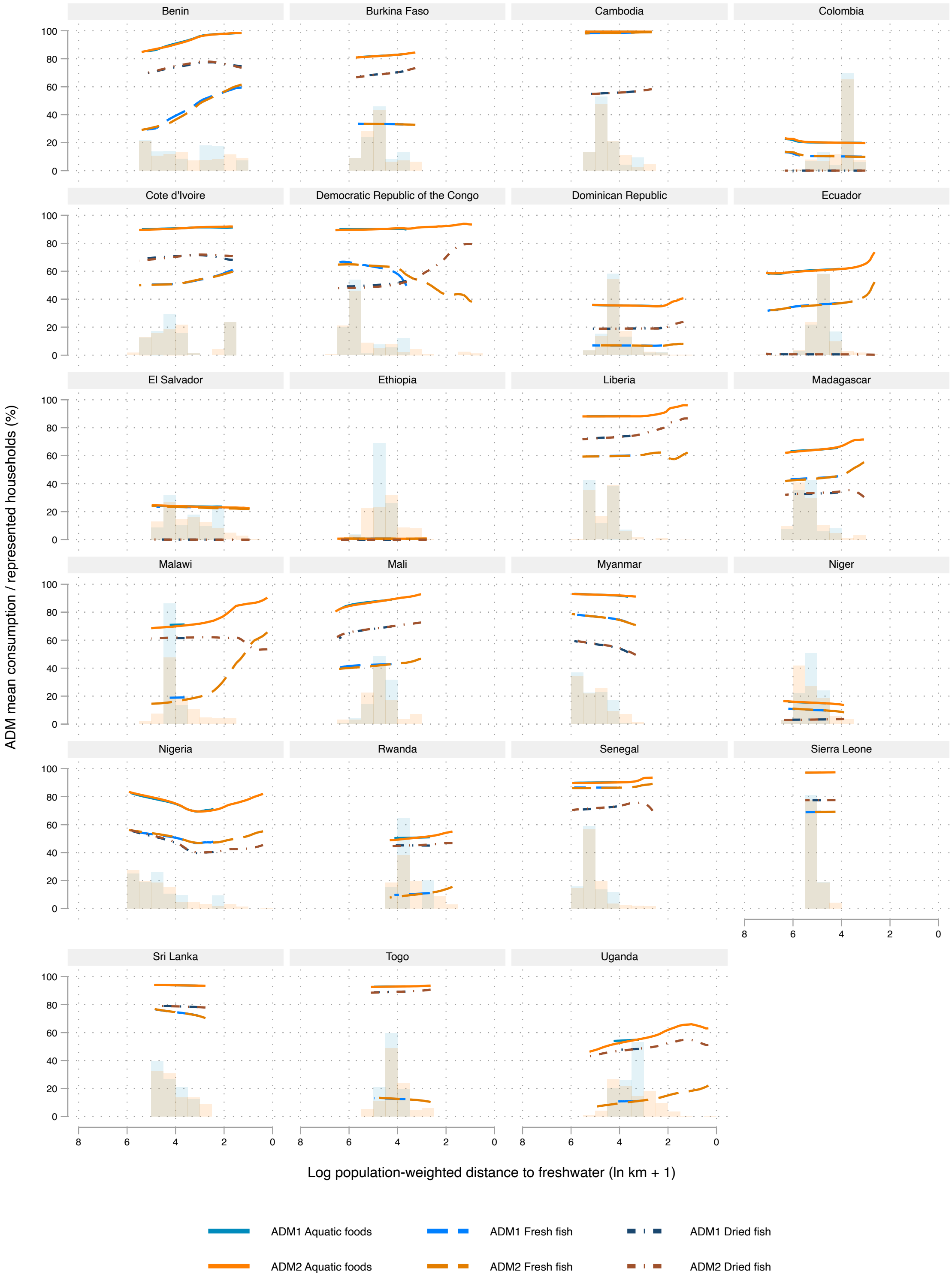


Fig. S14 | Freshwater exposure gradients are compared across ADM1 and ADM2 exposure assignments. Country panels compare unadjusted ADM1- and ADM2-level smooths for population-weighted distance to qualifying freshwater resources. The sample is restricted to countries with named ADM2 regions and qualifying freshwater exposure. Household outcomes are collapsed separately to ADM1 and ADM2 region means, and regions are weighted by represented household population.

3. Consumption among extremely poor households

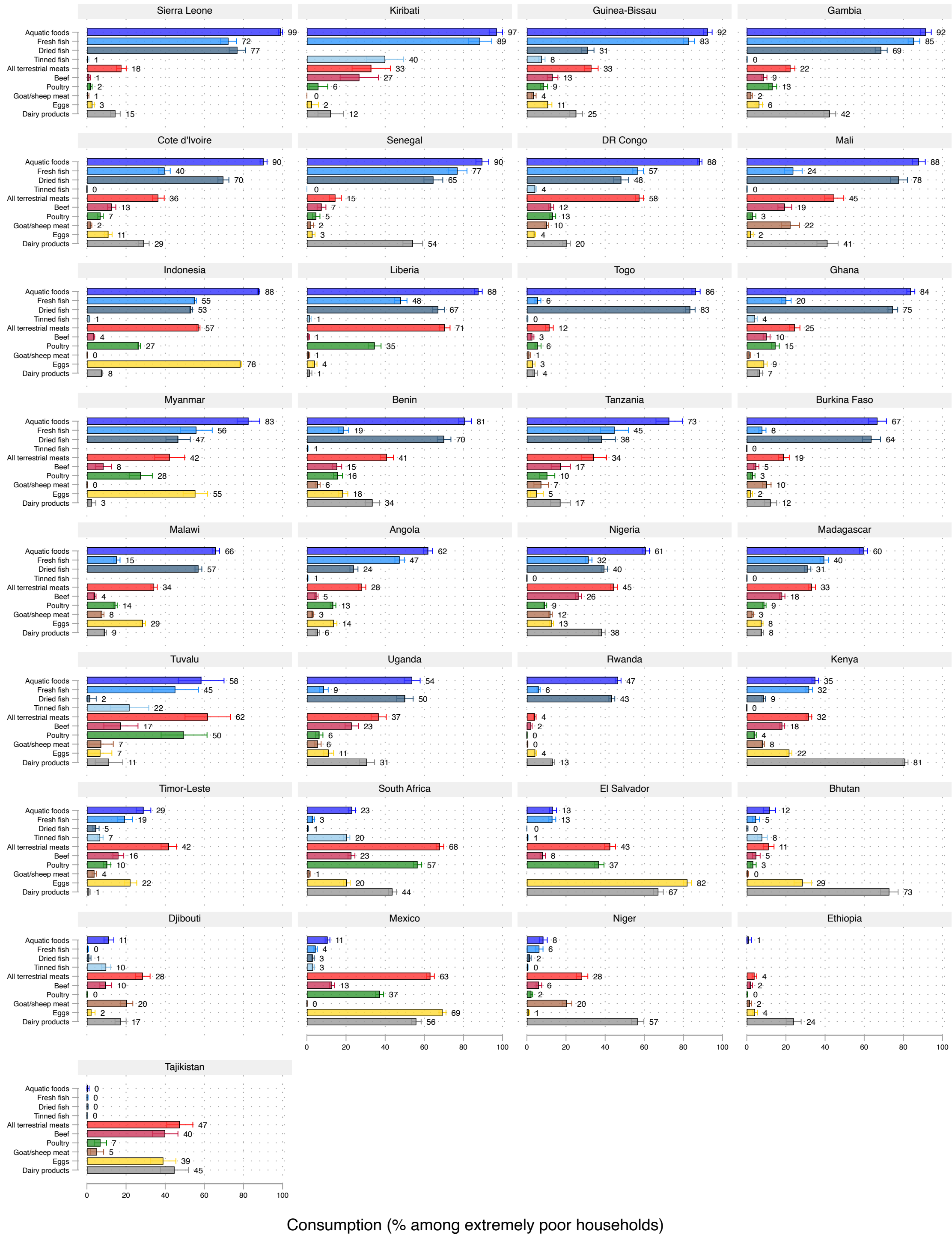


Fig. S15 | Consumption of animal-source foods among extremely poor households. Bars depict consumption of the different types of animal-source foods in the past seven days among households living in extreme poverty (<US$3.00 per person per day in 2021 PPPs) by country. We only include countries in which at least 5% of households fall below this threshold, ensuring sufficient representation of extremely poor households. Caps indicate 95% confidence intervals. Countries are ordered by the proportion of aquatic food consumption with higher shares at the top. Estimates account for survey design.

4. Global consumption gradients

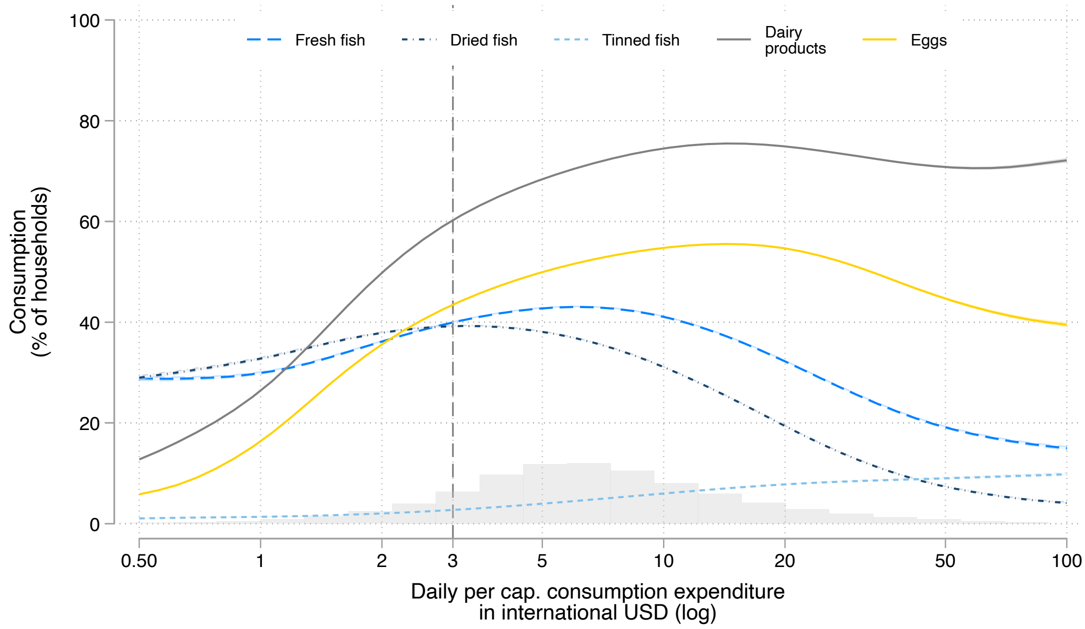


Fig. S16 | Other animal-source food consumption and household consumption expenditure. Lines show weighted local-polynomial estimates of the share of households consuming fresh fish, dried fish, tinned fish, milk and dairy, and eggs in the past week by daily per capita consumption expenditure. Fits are estimated using log daily per capita expenditure and an Epanechnikov kernel with bandwidth 0.5, restricted to households between $0.50 and $100 per person per day; x-axis labels show retransformed daily international USD values. The dashed vertical line marks $3.00 per person per day. Estimates use population-adjusted household survey weights. India is missing for fresh/dried/tinned fish and Myanmar is missing for tinned fish (see 'Methods').

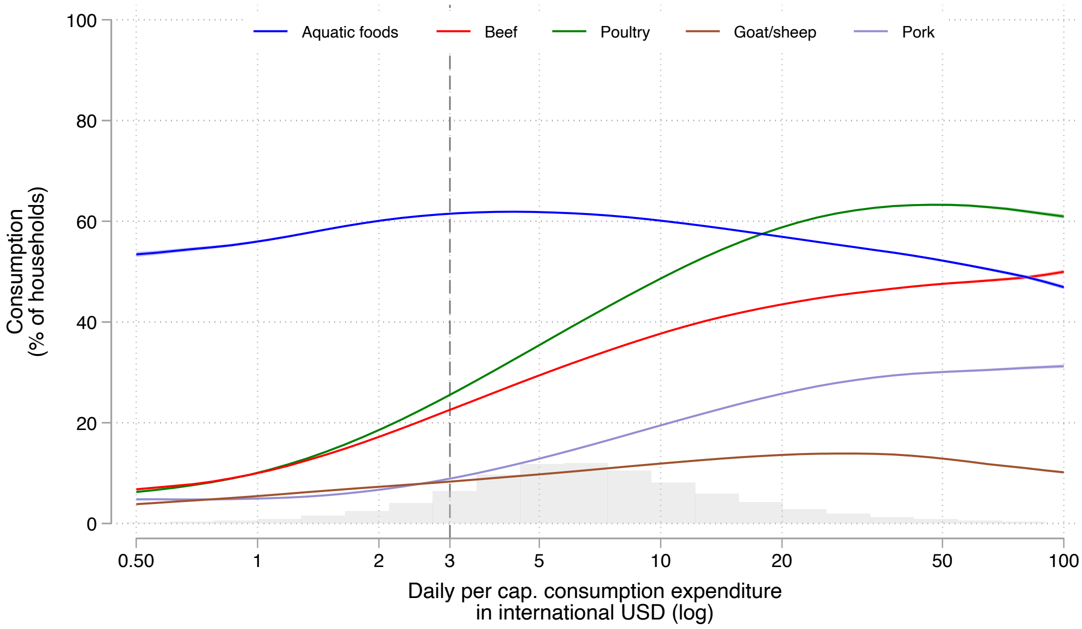


Fig. S17 | Animal-source food consumption and household consumption expenditure, equal country weights. Lines show local-polynomial estimates of the share of households consuming aquatic foods, beef, poultry, goat/sheep meat, and pork in the past week by daily per capita consumption expenditure, using weights that give each country equal total weight rather than weighting countries proportional to population. Fits are estimated using log daily per capita expenditure and an Epanechnikov kernel with bandwidth 0.5, restricted to households between \$0.50 and \$100 per person per day (n = 1,258,120). x-axis labels show retransformed daily international USD values. The dashed vertical line marks \$3.00 per person per day.

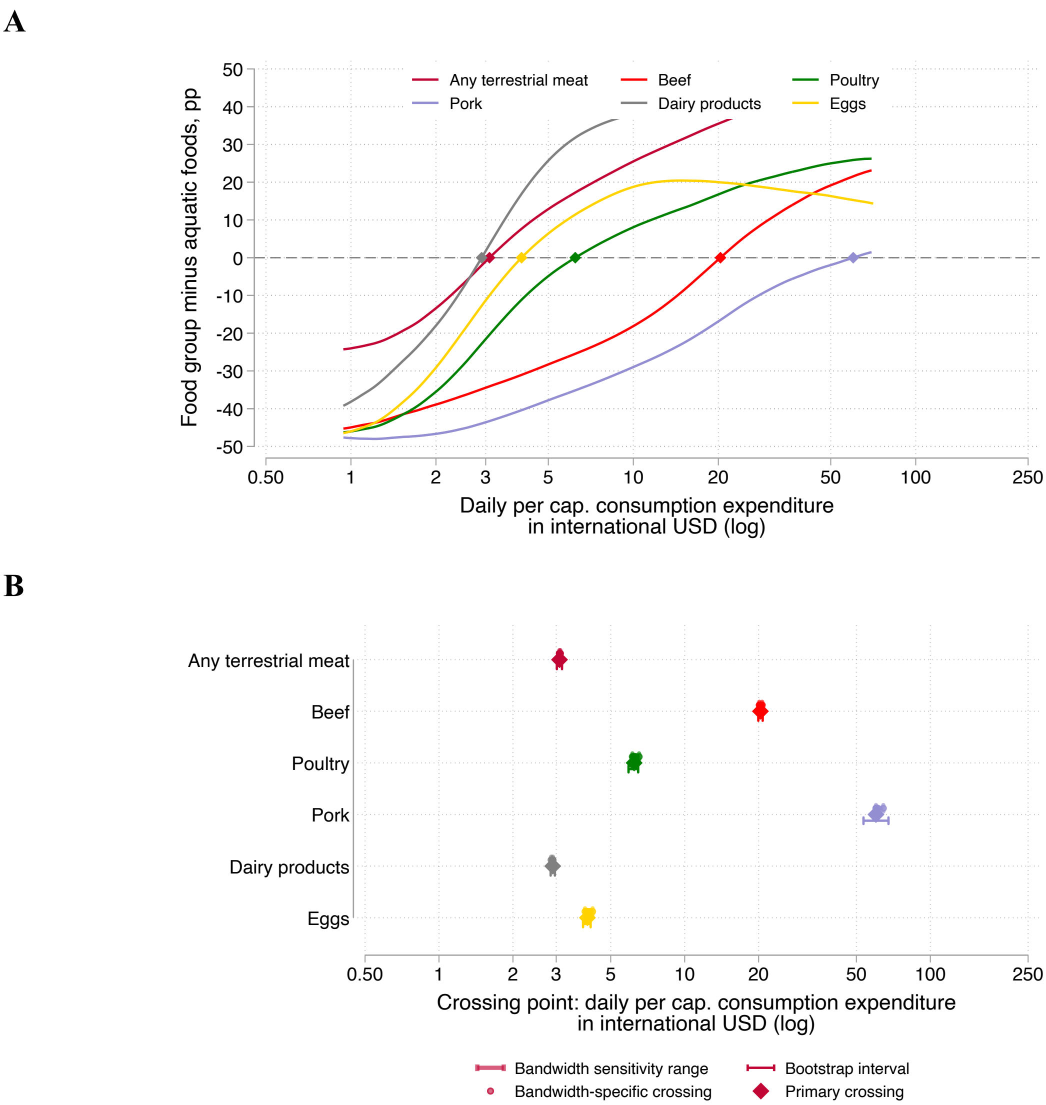


Fig. S18 | Expenditure levels at which terrestrial animal-source foods overtake aquatic foods. **A**, Smoothed differences in consumption probability between each food group and aquatic foods across daily per capita consumption expenditure. Values above zero indicate that the food group is more commonly consumed than aquatic foods. Curves are local-linear estimates using an Epanechnikov kernel with bandwidth 0.50 in log daily expenditure units; the x-axis is estimated on log expenditure but labeled in retransformed daily international dollars. Diamonds mark the first durable crossing point, defined as the expenditure level at which the fitted difference becomes positive and remains nonnegative over the higher-expenditure support. **B**, Robustness of estimated crossing points. Diamonds show the primary crossing estimates, circles show estimates from alternative bandwidths (0.25-1), light horizontal bars show the range across bandwidths, and dark bars show 95% bootstrap intervals from 500 clustered bootstrap replications. The smoother is evaluated over the 1st to 99th percentiles of log daily expenditure to reduce tail influence.

5. Within-country consumption gradients

Fig. S19 | Country-level animal-source food consumption and household consumption expenditure. Colors indicate the (unconditional) proportion of households that consumed each food group within the past week. 95% design-based confidence intervals (CIs) are shown in light colors. Countries are listed in order of average consumption of aquatic foods, with the lowest consumption first (Ethiopia) and the highest last (Cambodia). For the local polynomials, we use a bandwidth of 0.2. The x-axis shows logarithmized per-capita-per-day household consumption expenditure in USD (2021 Purchasing Power Parities), winsorized at the 5th and 95th percentiles. Light gray histograms depict household density.

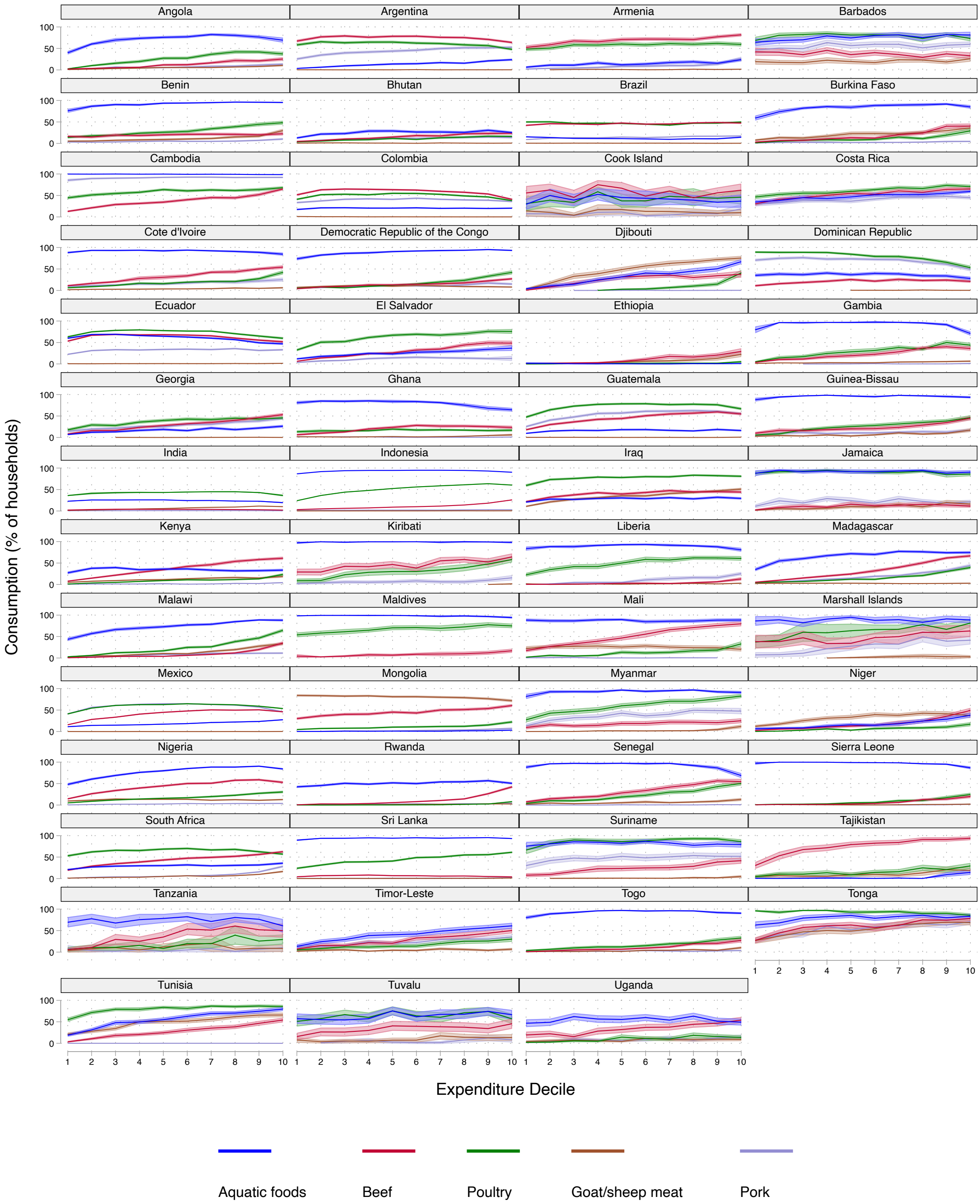


Fig. S20 | Consumption of animal-source foods across consumption expenditure deciles. The figure shows the proportion of households consuming different animal-source foods within each per-capita household consumption expenditure decile, by country. Estimates represent unconditional consumption averages, calculated as the share of households reporting consumption of each food group over the reference period within each decile. Consumption deciles are defined within countries based on per-capita household consumption expenditure. Points denote mean consumption prevalence, and vertical bars indicate 95% confidence intervals. Estimates account for survey sampling weights where applicable.

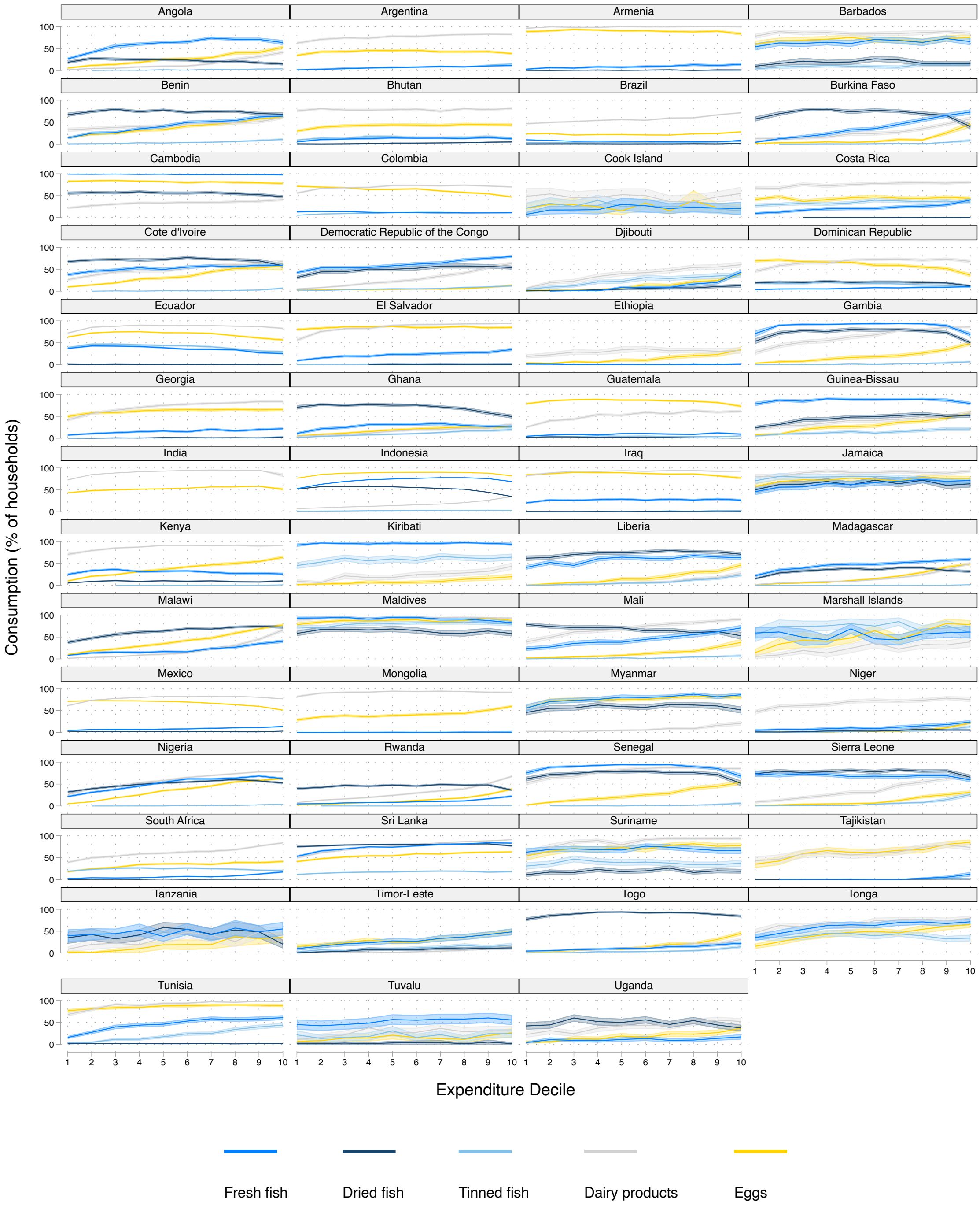


Fig. S21 | Consumption of fish products and other animal-source foods across consumption expenditure deciles. The figure shows the proportion of households consuming different animal-source foods within each per-capita household consumption expenditure decile, by country. Estimates represent unconditional consumption averages, calculated as the share of households reporting consumption of each food group over the reference period within each decile. Consumption deciles are defined within countries based on per-capita household consumption expenditure. Points denote mean consumption prevalence, and vertical bars indicate 95% confidence intervals. Estimates account for survey sampling weights where applicable.

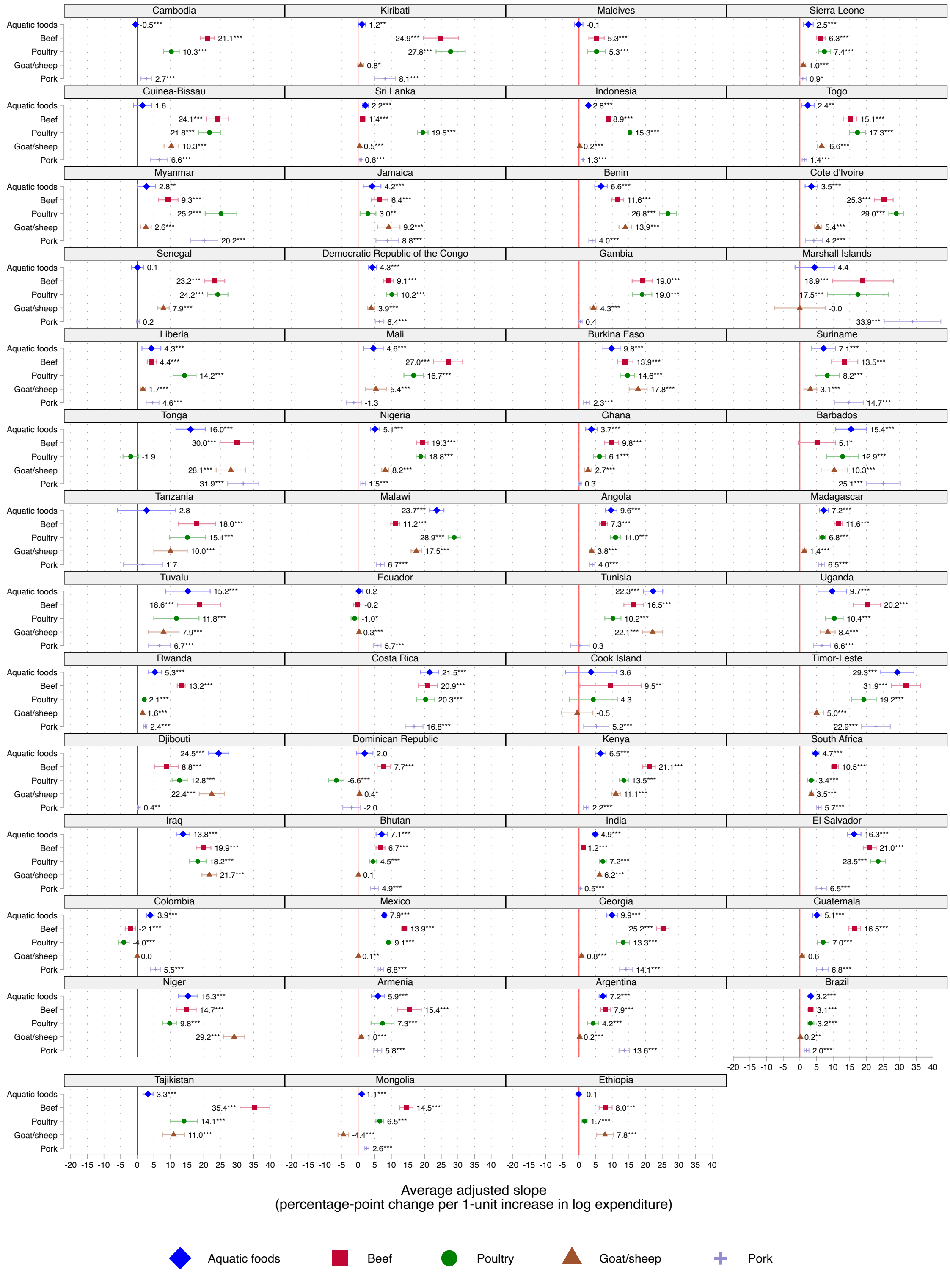


Fig. S22 | Average adjusted welfare gradients in animal-source foods. Points show country-specific average marginal effects from survey-weighted logistic regressions of food-group consumption on log per capita consumption expenditure, adjusted for ADM1 fixed effects, survey month, household size, household-head age, sex, education, urban residence, and agricultural occupation. Horizontal bars indicate 95% confidence intervals. Effects are shown as percentage-point changes in consumption probability for a one-unit increase in log expenditure.

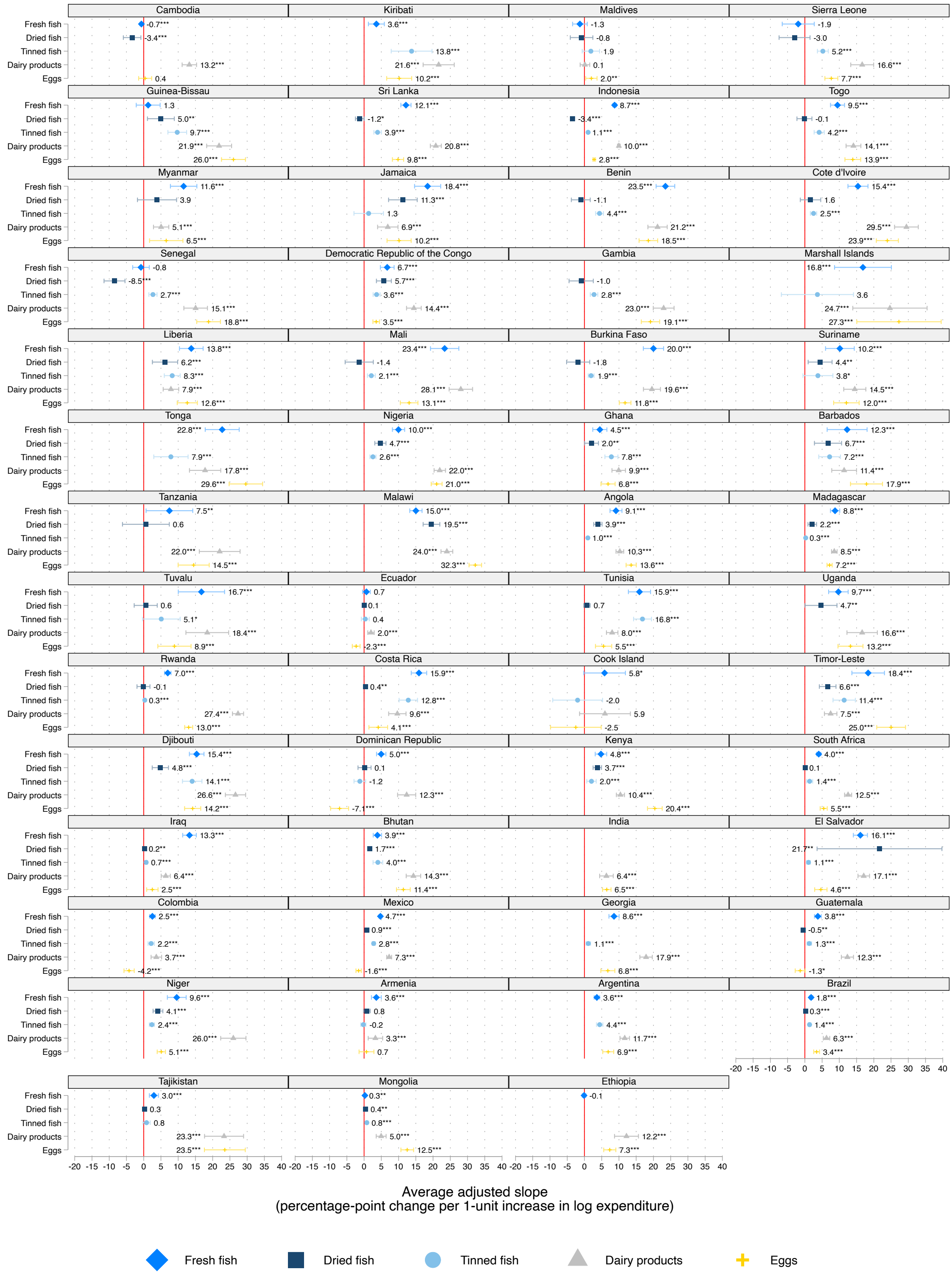


Fig. S23 | Average adjusted welfare gradients in fish-processing categories, dairy, and eggs. Points show country-specific average marginal effects from survey-weighted logistic regressions of food-group consumption on log per capita consumption expenditure, adjusted for ADM1 fixed effects, survey month, household size, household-head age, sex, education, urban residence, and agricultural occupation. Horizontal bars indicate 95% confidence intervals. Effects are shown as percentage-point changes in consumption probability for a one-unit increase in log expenditure.

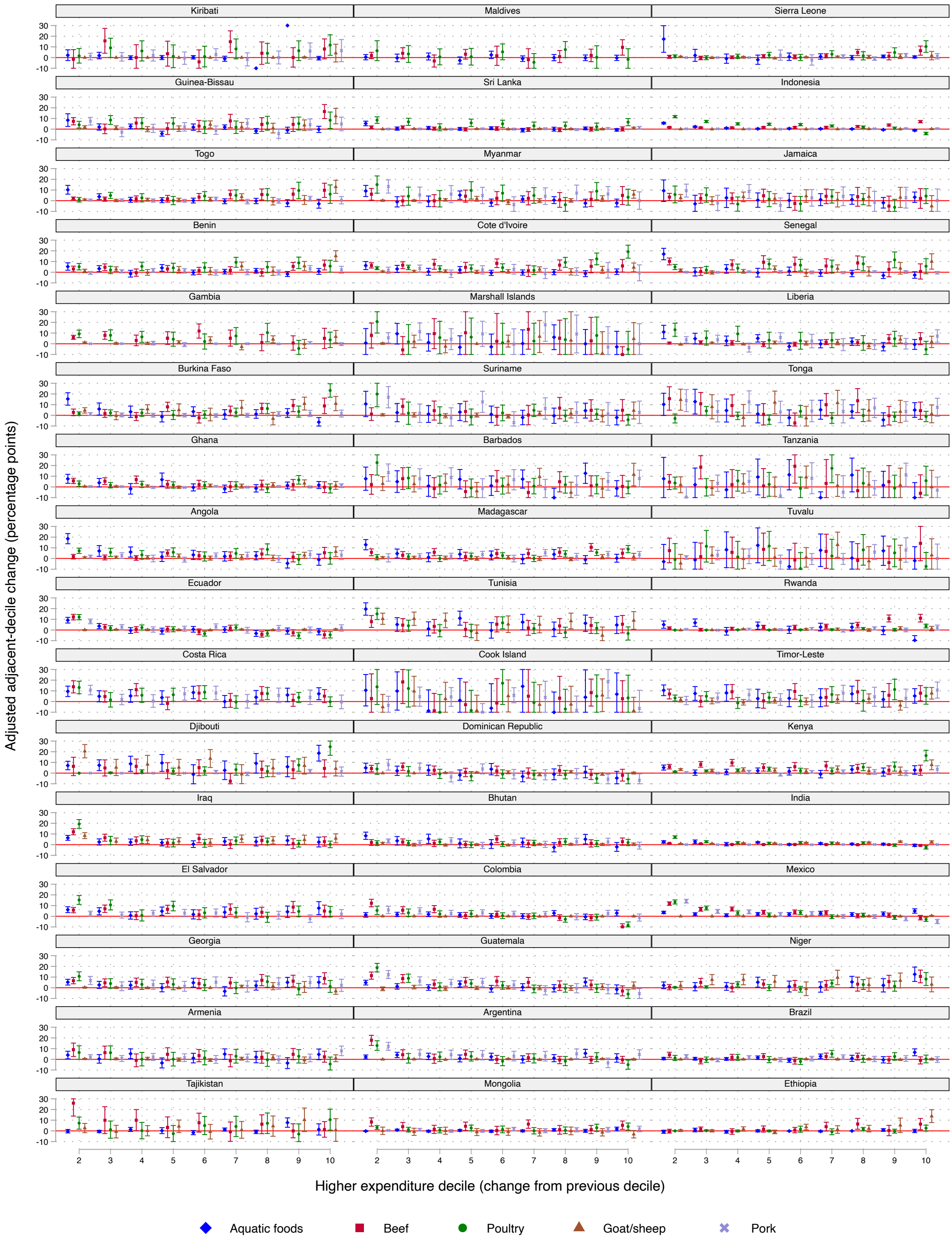


Fig. S24 | Where animal-source food consumption changes along the expenditure distribution. Symbols show adjacent changes in adjusted predicted consumption probabilities between expenditure deciles. Estimates are from survey-weighted country-specific logistic regressions with expenditure decile indicators and the same household and fixed-effect controls as in Fig. S22. Caps indicate 95% confidence intervals calculated from the covariance matrix of the adjusted decile-specific predictions. Small Pacific Island states, El Salvador and Tanzania were dropped from this graph due to large confidence intervals to improve visibility.

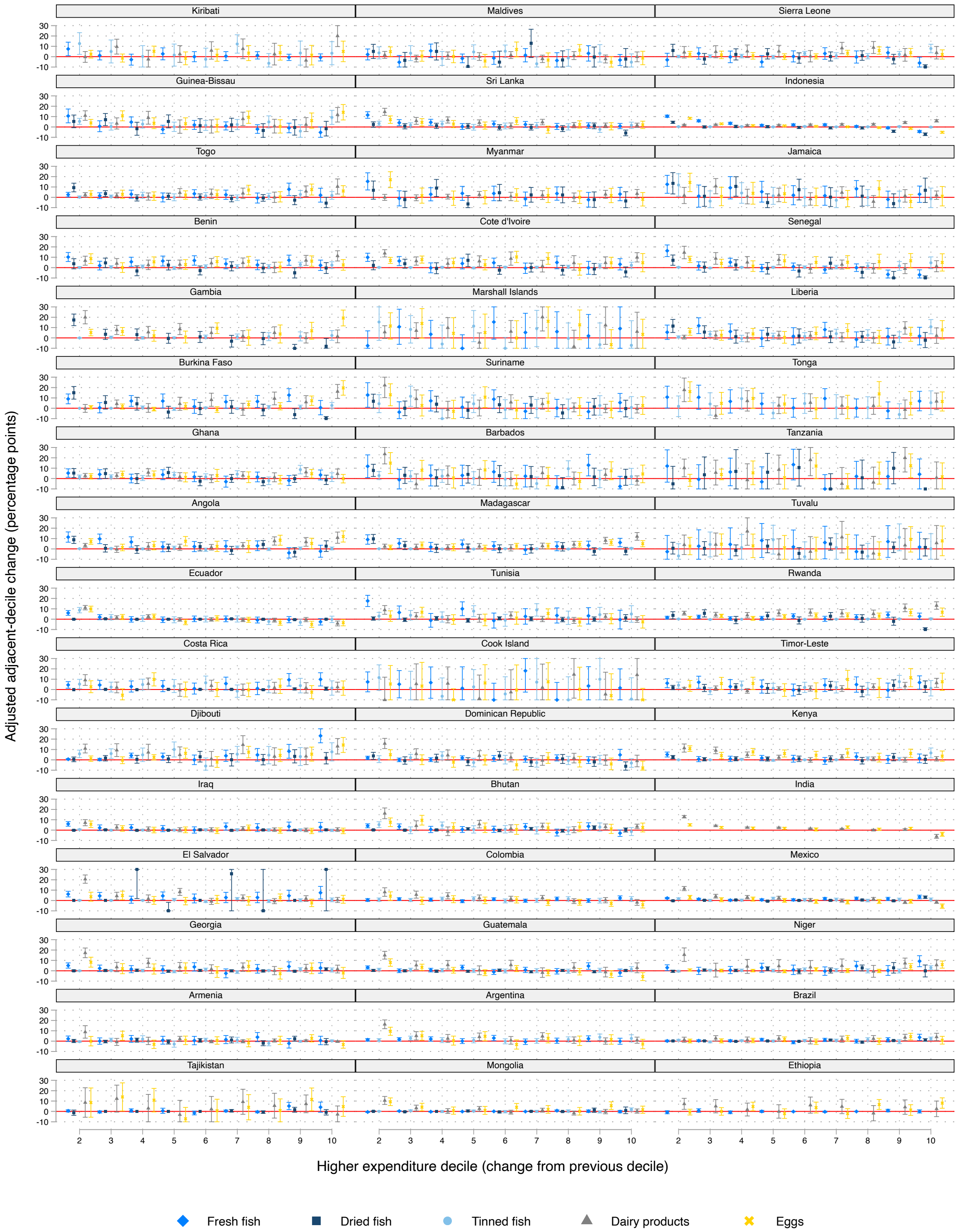


Fig. S25 | Where fish-processing categories, dairy, and eggs change along the expenditure distribution. Symbols show adjacent changes in adjusted predicted consumption probabilities between expenditure deciles. Estimates are from survey-weighted country-specific logistic regressions with expenditure decile indicators and the same household and fixed-effect controls as in Fig. S23. Caps indicate 95% confidence intervals calculated from the covariance matrix of the adjusted decile-specific predictions. Small Pacific Island states, El Salvador and Tanzania were dropped from this graph due to large confidence intervals to improve visibility.

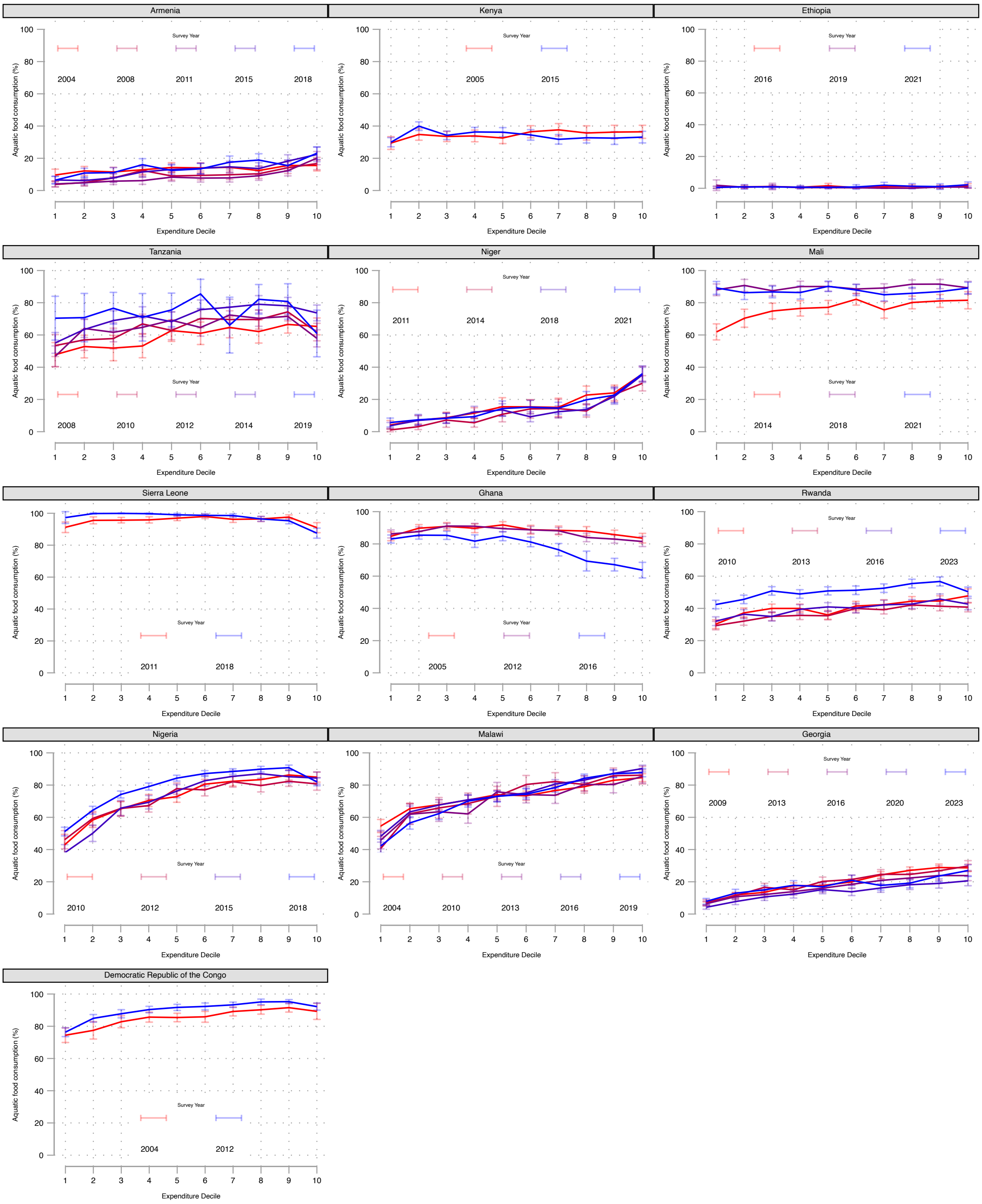


Fig. S26 | Income gradient of aquatic food consumption over time. All estimates account for survey sampling design and household weights. Spikes indicate 95% confidence intervals. Consumption deciles are defined based on per capita household consumption expenditure within countries. Countries were selected based on at least two available cross-sectional waves with comparable data spanning at least five years.

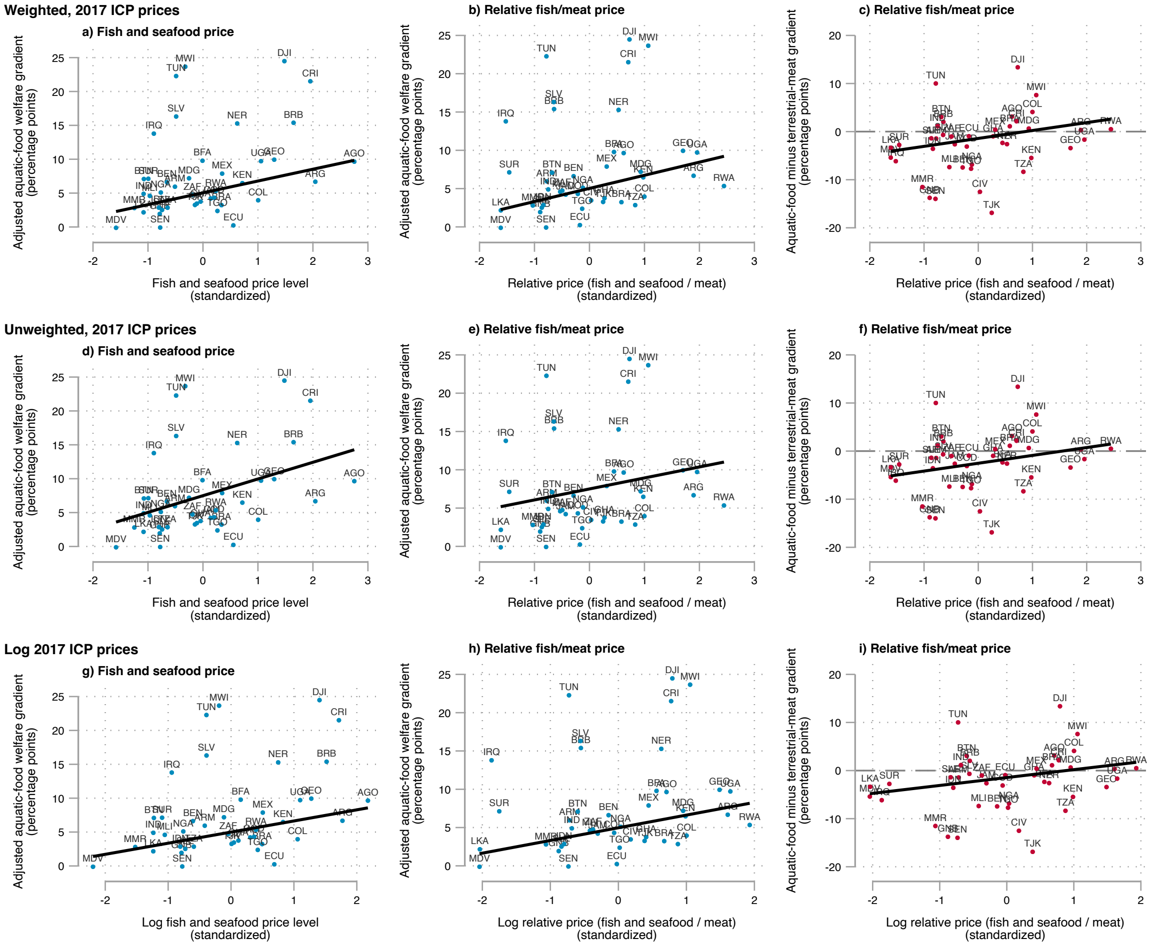


Fig. S27 | National fish prices and aquatic food welfare gradients. Country-level associations between national fish and seafood price levels and adjusted welfare gradients in aquatic food consumption. Labels show ISO3 codes. The y-axis in panels a, b, d, e, g, and h is the adjusted aquatic food welfare gradient, defined as the percentage-point change in the probability of aquatic food consumption associated with a one-unit increase in log per capita consumption expenditure. The y-axis in panels c, f, and i is the difference between the aquatic food gradient and the average terrestrial-meat gradient. Positive values indicate that aquatic food consumption rises more strongly with household expenditure than terrestrial-meat consumption. Prices are from the 2017 International Comparison Program and are standardized across countries. Panels a-c use inverse-variance weighted country regressions; panels d-f give equal weight to each country; panels g-i use log-transformed price measures. Fitted lines are linear associations.

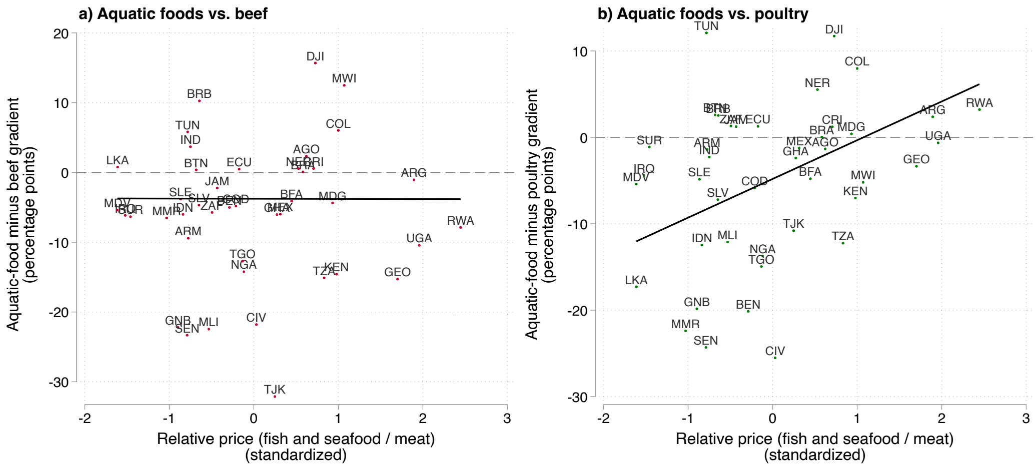


Fig. S28 | Relative fish prices and aquatic food welfare gradients compared with beef and poultry. Country-level associations between the relative price of fish and seafood and differences in adjusted welfare gradients across animal-source food groups. Labels show ISO3 codes. The x-axis is the standardized 2017 ICP price of fish and seafood relative to aggregate meat. The y-axis shows the adjusted aquatic food welfare gradient minus the adjusted beef gradient in panel a and minus the adjusted poultry gradient in panel b. Positive values indicate that aquatic food consumption is more strongly concentrated among higher-expenditure households than beef or poultry consumption. Fitted lines are inverse-variance weighted linear associations.

6. Contribution to dietary diversity

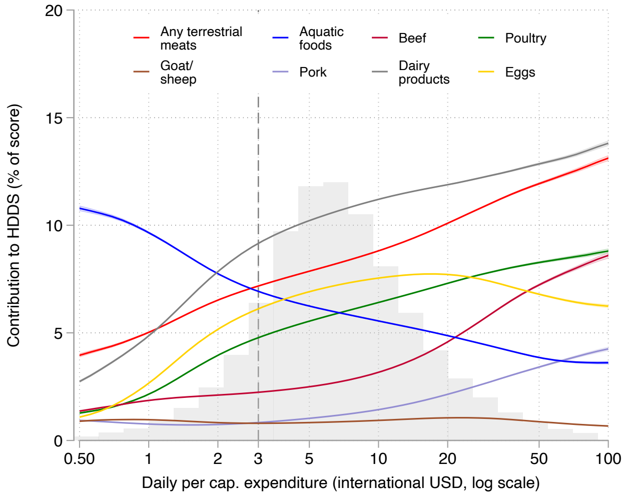


Fig. S29 | Contribution of animal-source foods to Household Dietary Diversity Score (HDDS) along the global expenditure gradient. Lines show weighted local polynomial smooths of each food group's contribution to the Household Dietary Diversity Score (HDDS), expressed as percent of the score, across log daily per capita consumption expenditure in international dollars. Shaded bands indicate 95% confidence intervals. Gray histograms show the weighted distribution of households across the expenditure range and are rescaled for display.

Fig. S30 | Contribution of animal-source foods to dietary diversity across household expenditure gradients by country. Lines show weighted local polynomial smooths of each food group's contribution to the Minimum Dietary Diversity for Women score (MDD-W), expressed as percent of the score, across log daily per capita consumption expenditure in international dollars. Shaded bands indicate 95% confidence intervals. Gray histograms show the weighted distribution of households across the expenditure range within each country and are rescaled for display. Countries are ordered by the average contribution of aquatic foods to MDD-W. Expenditure is winsorized within surveys at the 5th and 95th percentiles.

7. Expenditure shares

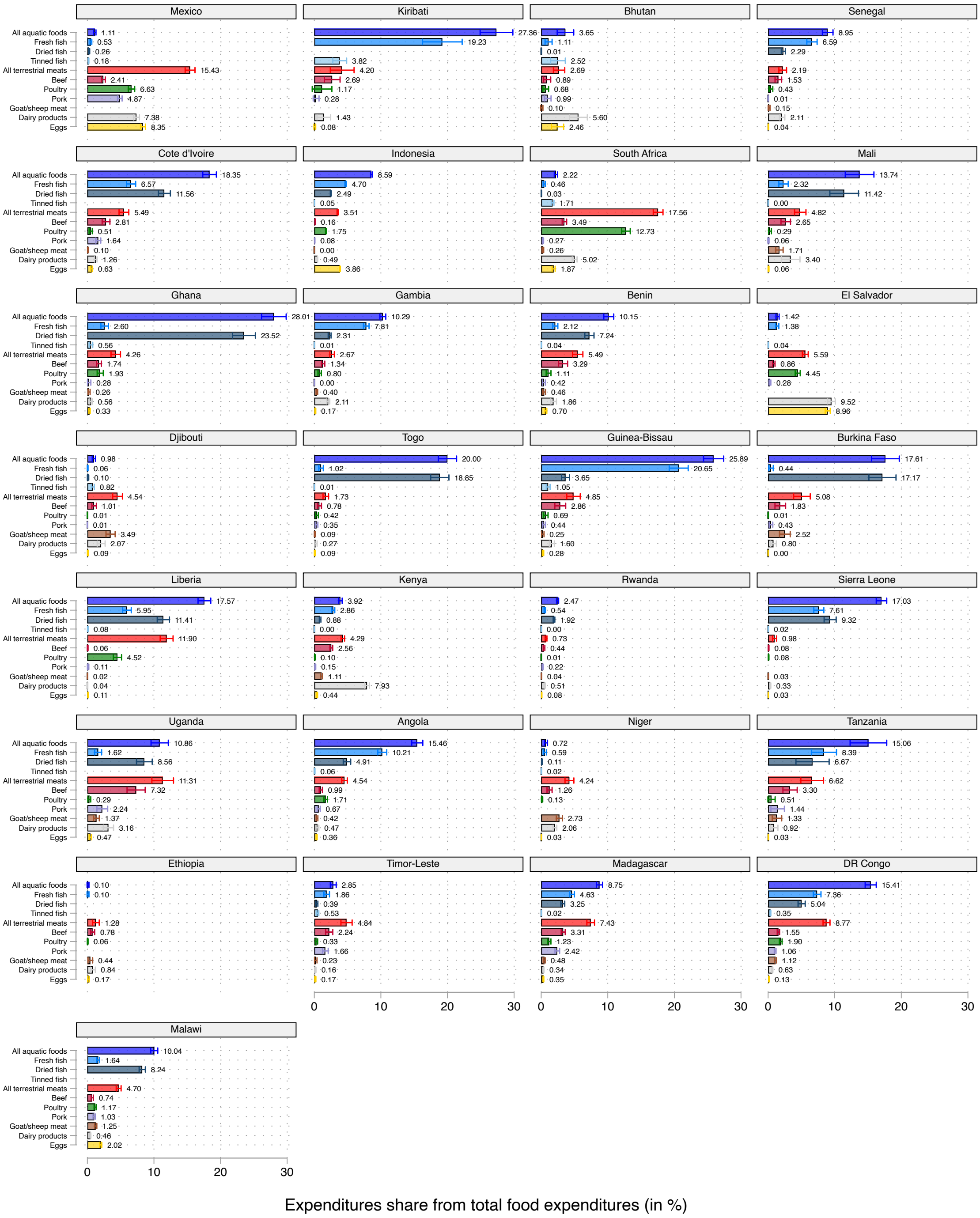


Fig. S31 | Food expenditure shares among extremely poor households by country. Bars show mean shares of total food expenditure allocated to selected animal-source food groups among extremely poor households, by country. Extremely poor households are defined as households with daily per capita consumption expenditure below $3.00 in international USD. Countries are included if at least 5% of sampled households are extremely poor. Expenditure shares are calculated as spending on each food group divided by total food expenditure. Error bars show 95% design-based confidence intervals. Estimates use survey design information and population-adjusted household weights, so each survey contributes in proportion to the country population in the survey year. Countries are ordered by the weighted share of extremely poor households.

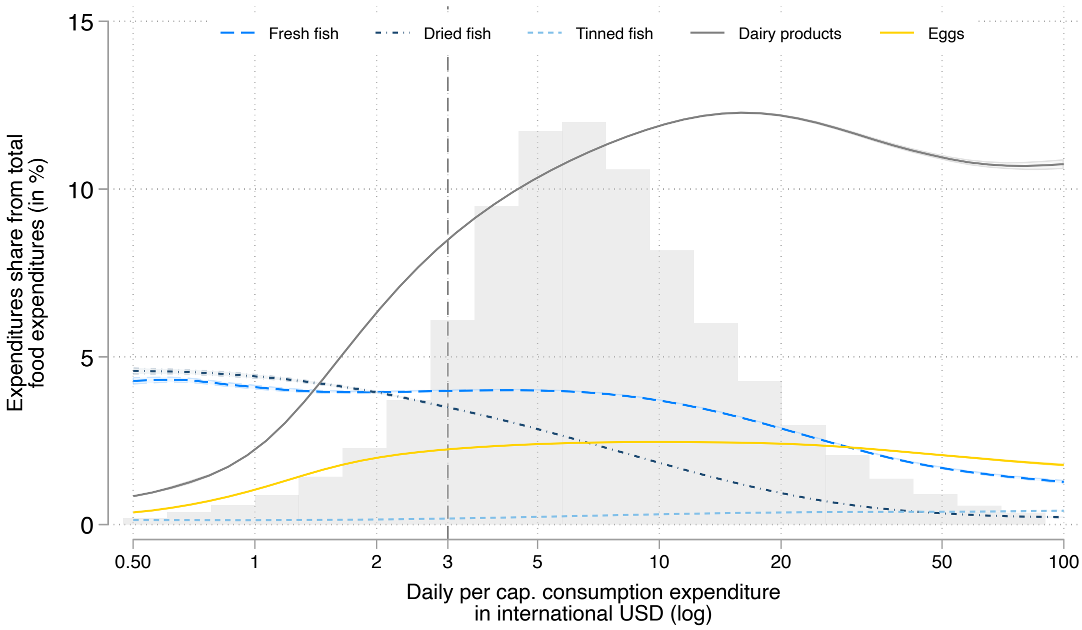


Fig. S32 | Expenditure shares for fish types, dairy, and eggs across the global expenditure distribution. Lines show local-polynomial fits (bandwidth 0.5) between food expenditure shares and daily per capita consumption expenditure. The x-axis is plotted on the log scale and labeled in retransformed international USD per person per day. Expenditure shares are calculated as spending on each food group divided by total food expenditure. Local-polynomial fits use population-adjusted household weights and shaded areas show confidence intervals. The vertical dashed line marks the US$3.00-per-day threshold for extreme poverty, and the gray histogram shows the weighted distribution of households across expenditure levels.

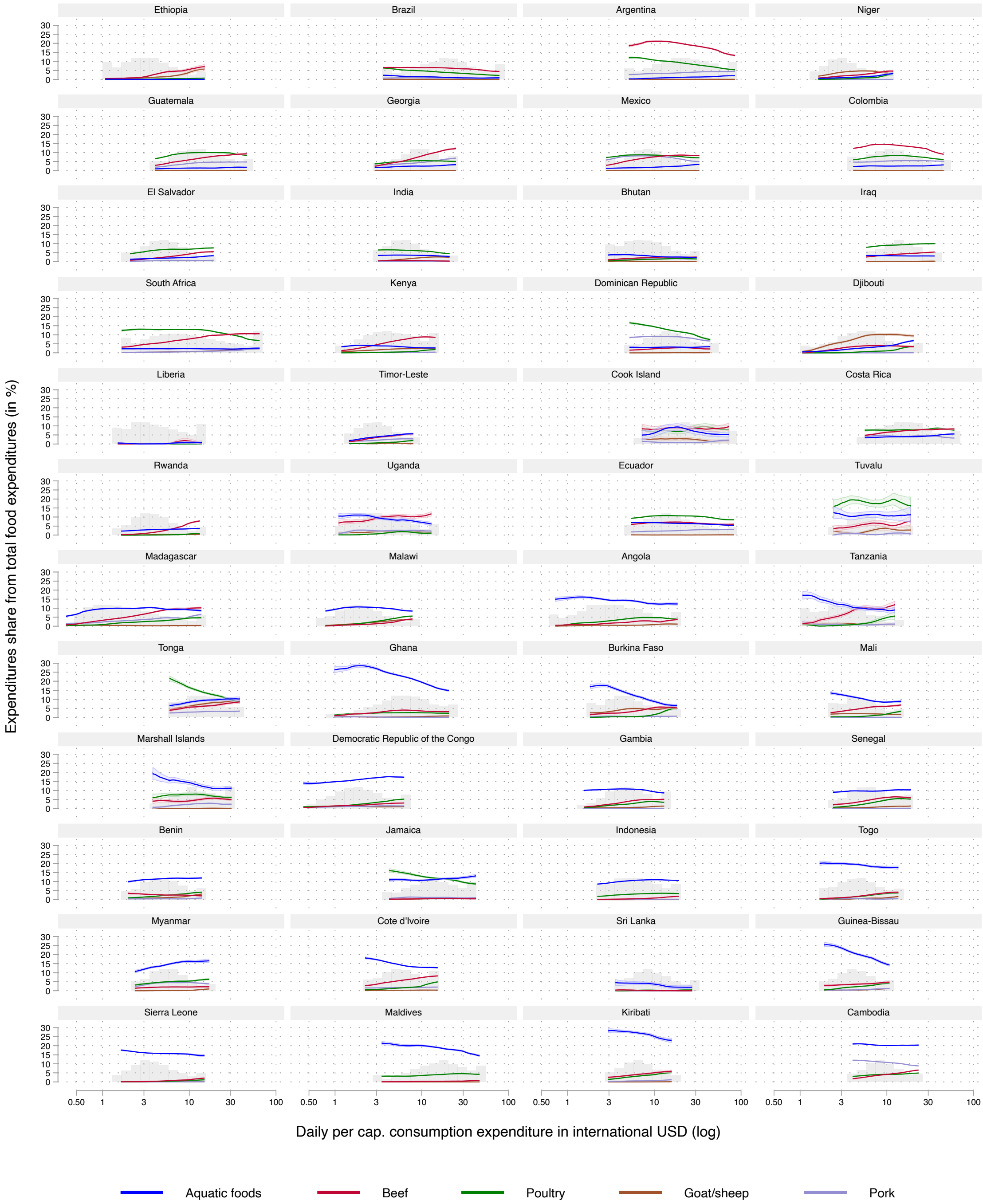


Fig. S33 | Country-specific food expenditure shares across the welfare distribution.
Lines show local-polynomial smooths of food-group expenditure shares use Epanechnikov kernel smoothing with bandwidth 0.2 against daily per capita consumption expenditure, estimated separately by country. Outcomes are expressed as shares of total food expenditure. Household weights are adjusted so each survey represents the country population in the survey year. The x-axis is plotted on the log scale, with labels shown as retransformed daily international USD values. Shaded areas indicate 95% confidence intervals. Gray histograms show the weighted distribution of households across the expenditure range within each country.

Fig. S34 | Country-specific expenditure shares for fish-processing types, dairy, and eggs across the welfare distribution.
Lines show local-polynomial smooths of food-group expenditure shares using use Epanechnikov kernel smoothing with bandwidth 0.2 against daily per capita consumption expenditure, estimated separately by country. Outcomes are expressed as shares of total food expenditure. Household weights are adjusted so each survey represents the country population in the survey year. The x-axis is plotted on the log scale, with labels shown as retransformed daily international USD values. Shaded areas indicate 95% confidence intervals. Gray histograms show the weighted distribution of households across the expenditure range within each country.

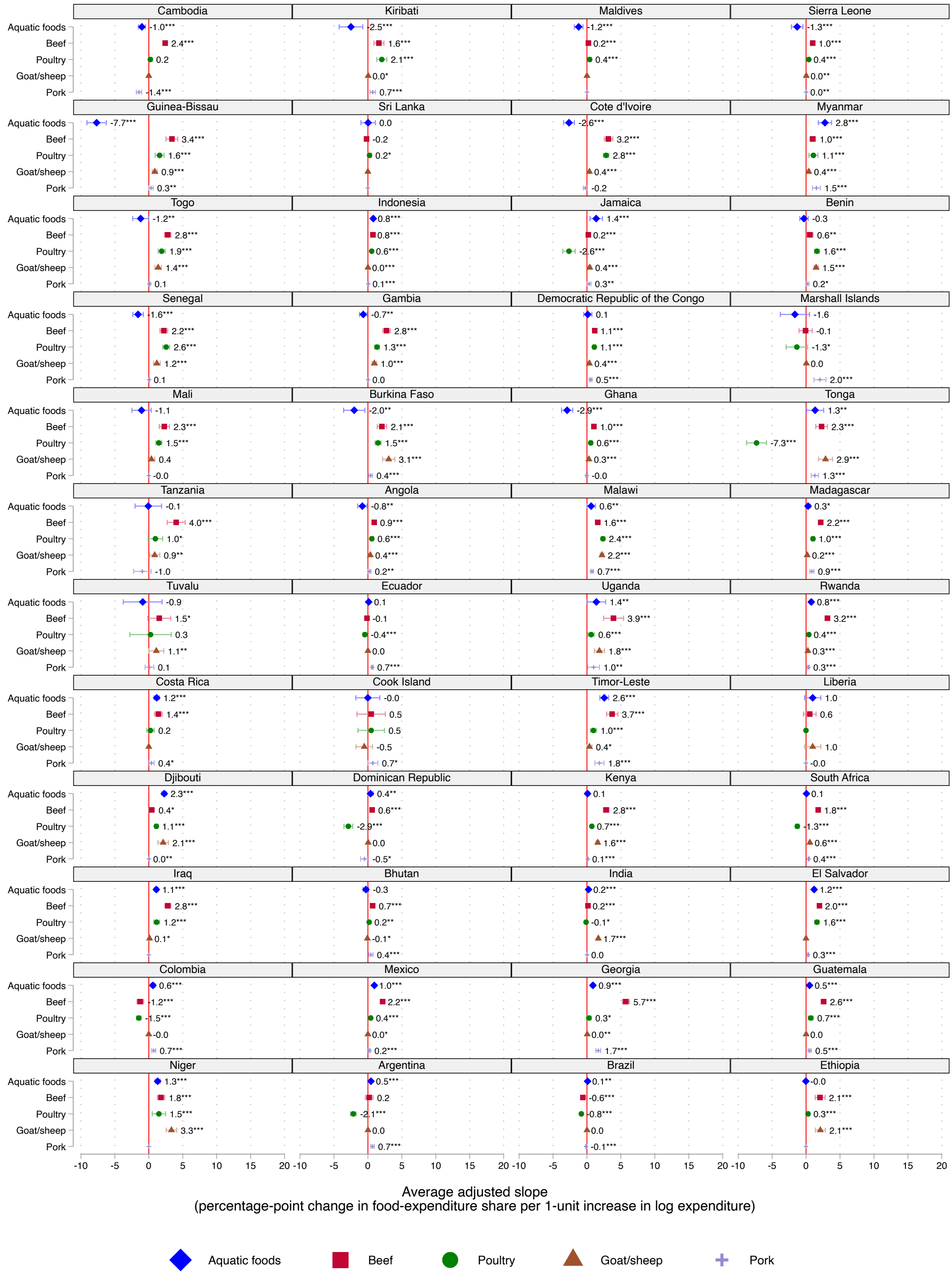


Fig. S35 | Adjusted welfare gradients in food expenditure shares across countries. Points denote country-specific adjusted slopes from survey-weighted linear regressions of food-group expenditure shares on log annual per capita consumption expenditure. Outcomes are expressed as shares of total food expenditure. Models adjust for ADM1 fixed effects, survey month, household size, household-head age, sex, education, urban residence, and agricultural occupation. Horizontal bars indicate 95% confidence intervals. Positive values indicate that the food group accounts for a larger share of food expenditure among higher-expenditure households. Food categories unavailable in a country survey are left blank.

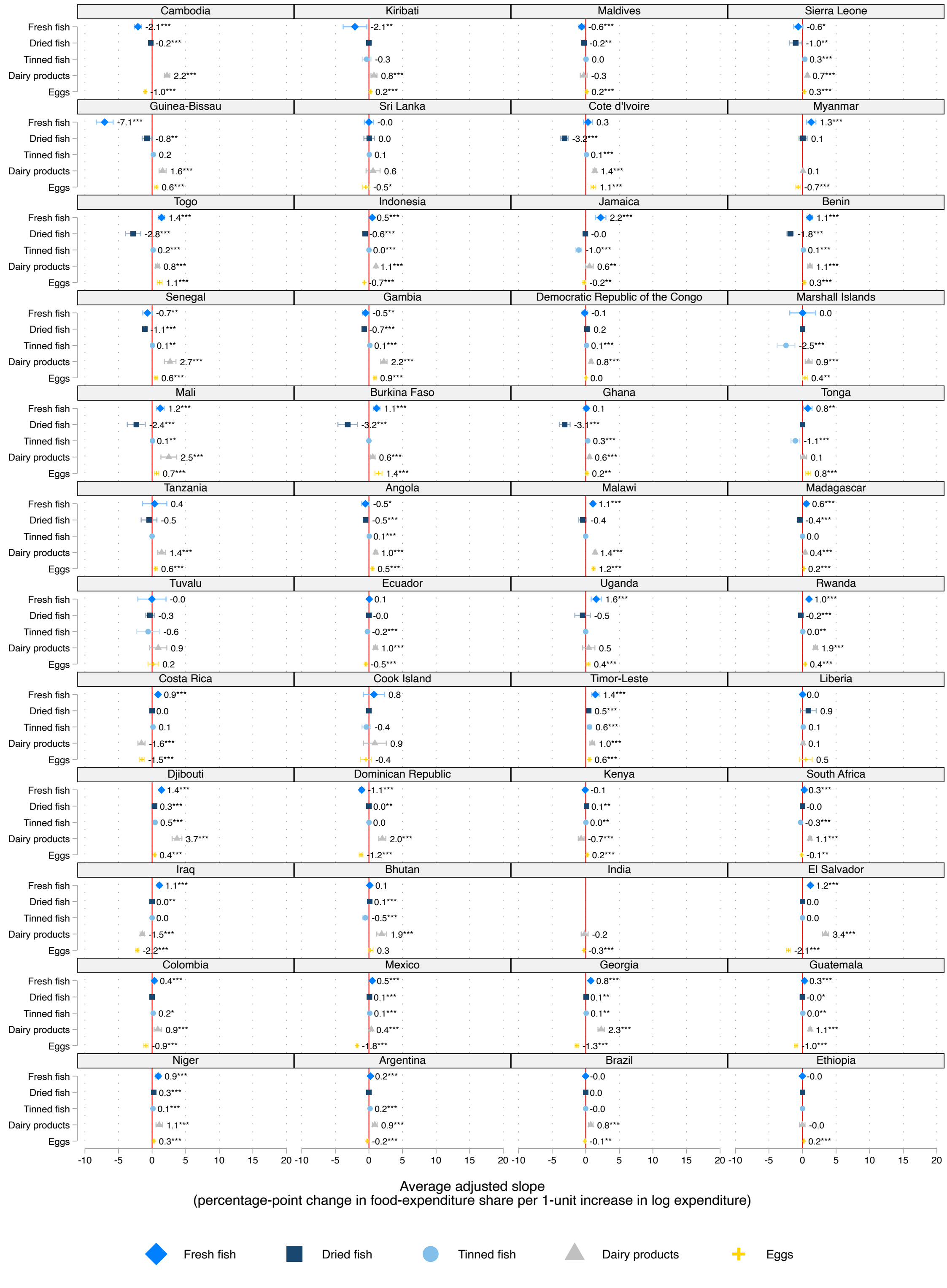


Fig. S36 | Adjusted welfare gradients in fish-processing, dairy, and egg expenditure shares.
Points denote country-specific adjusted slopes from survey-weighted linear regressions of expenditure shares for fresh fish, dried fish, tinned fish, dairy products, and eggs on log annual per capita consumption expenditure. Outcomes are percentage-point shares of total food expenditure. Models include ADM1 fixed effects and the same household controls as in the main expenditure-share slope figure. Horizontal bars indicate 95% confidence intervals. Categories not collected or structurally unavailable in a country survey are not plotted.

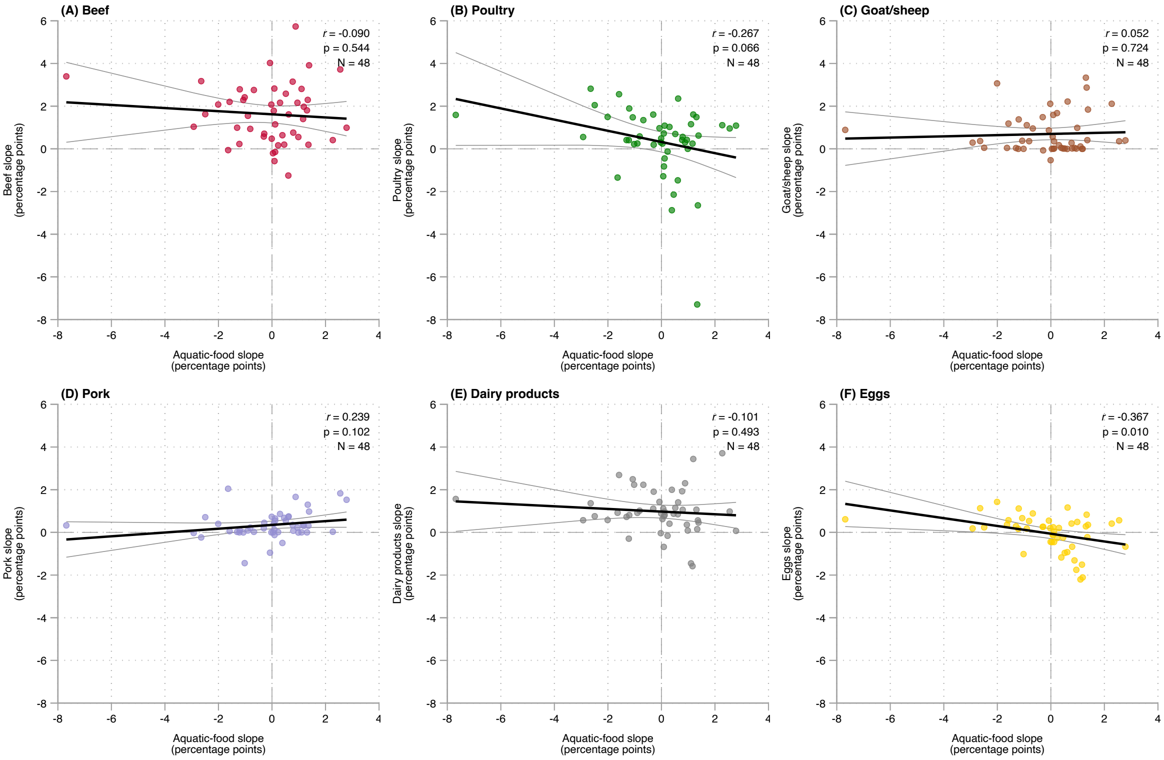


Fig. S37 | Country-level correlations in expenditure-share gradients for aquatic foods and other animal-source foods.

Each point represents one country. The x-axis shows the adjusted slope for aquatic foods, and the y-axis shows the corresponding adjusted slope for beef, poultry, goat/sheep, pork, dairy products, or eggs. Slopes are measured as percentage-point changes in the food-group expenditure share associated with a one-unit increase in log per-capita expenditure. Black lines show unweighted linear fits. Gray bands show 95% confidence intervals. Reported *r* values are unweighted Pearson correlation coefficients across countries with non-missing slope estimates for both food groups. *p* values refer to tests of zero correlation.

8. Tables

Table S1 | Data information

Country Name	ISO3-Code	Survey Name	Start Year	End Year	Population (in 1,000)	Sample Size
Angola	AGO	Inquérito Sobre Despesas, Receitas e Emprego em Angola	2018	2019	31,831	12,448
Argentina	ARG	Encuesta Nacional de Gastos de los Hogares	2017	2018	44,479	21,107
Armenia	ARM	Integrated Living Conditions Survey	2018	2018	2,910	5,096
Barbados	BRB	Barbados Survey of Living Conditions	2016	2017	280	2,365
Benin	BEN	Enquête Harmonisée sur le Conditions de Vie des Ménages	2021	2022	13,585	8,032
Bhutan	BTN	Living Standards Survey	2012	2012	717	8,968
Brazil	BRA	Consumer Expenditure Survey / Pesquisa de Orçamentos Familiares (POF)	2017	2018	205,431	49,799
Burkina Faso	BFA	Enquête Harmonisée sur le Conditions de Vie des Ménages	2021	2022	22,252	7,176
Cambodia	KHM	Cambodia Socio-Economic Survey	2023	2023	17,424	12,096
Colombia	COL	Encuesta Nacional de Presupuestos de los Hogares (ENPH)	2016	2017	47,702	82,511
Cook Island	COK	Household Income and Expenditure Survey 2015-2016 - 2015	2015	2016	17	678
Costa Rica	CRI	Encuesta Nacional de Ingresos y Gastos de los Hogares (ENIGH)	2018	2019	4,980	7,046
Cote d'Ivoire	CIV	Enquête harmonisée sur les conditions de vie des ménages (EHCVM)	2021	2022	30,006	12,965
DR Congo	COD	National Household Survey	2012	2013	74,484	14,977
Djibouti	DJI	Enquête Djiboutienne Auprès des Ménages	2017	2017	1,055	4,474
Dominican Republic	DOM	Encuesta Nacional de Gastos e Ingresos de los Hogares (ENGIH)	2018	2018	10,782	8,724
Ecuador	ECU	Encuesta Nacional de Ingresos y Gastos de Hogares Urbanos y Rurales	2011	2012	15,451	38,198
El Salvador	SLV	Encuesta de Hogares de Propósitos Múltiples (EHPM)	2014	2014	6,163	11,841
Ethiopia	ETH	Socioeconomic Survey	2019	2019	115,737	6,770
Gambia	GMB	Integrated Household Survey	2015	2016	2,254	13,281
Georgia	GEO	Households Incomes and Expenditures Survey	2023	2023	3,807	13,116
Ghana	GHA	Ghana Living Standard Survey	2016	2017	29,690	13,944
Guatemala	GTM	Encuesta Nacional de Empleo e Ingresos	2021	2022	17,711	13,747
Guinea-Bissau	GNB	Inquérito Harmonizado sobre as Condições de vide dos Agreagados Familiares	2021	2022	2,082	5,351
India	IND	Household Consumer Expenditure	2022	2023	1,431,703	261,552
Indonesia	IDN	Survei Sosial Ekonomi Nasional	2018	2018	269,952	295,155
Iraq	IRQ	Household Socio-Economic Survey	2012	2013	34,532	25,122
Jamaica	JAM	Jamaica Survey of Living Conditions	2019	2020	2,825	2,365
Kenya	KEN	Kenya Integrated Household Budget Survey	2015	2016	47,600	21,625
Kiribati	KIR	Household Income and Expenditure Survey	2019	2019	124	2,146
Liberia	LBR	Household Income and Expenditure Survey	2016	2017	4,802	8,350
Madagascar	MDG	Enquête périodique auprès des ménages	2021	2022	30,061	16,871
Malawi	MWI	Fifth Integrated Household Survey	2019	2020	19,278	11,434
Maldives	MDV	Household Income and Expenditure Survey	2019	2019	488	4,624
Mali	MLI	Enquête Harmonisée sur le Conditions de Vie des Ménages	2021	2022	22,729	6,138
Marshall Islands	MHL	Household Income and Expenditure Survey	2019	2020	43	872
Mexico	MEX	National Survey of Household Income and Expenditure (ENIGH)	2022	2022	128,613	89,402
Mongolia	MNG	Household Socio-Economic Survey	2021	2021	3,340	11,199
Myanmar	MMR	Poverty and Living Conditions Survey	2015	2015	51,089	3,648
Namibia	NAM	Household Income and Expenditure Survey	2015	2016	2,406	10,090
Niger	NER	Enquête Harmonisée sur le Conditions de Vie des Ménages	2021	2022	24,897	6,622
Nigeria	NGA	Living Standards Survey	2018	2019	207,230	22,117
Rwanda	RWA	Integrated Household Living Conditions Survey	2023	2024	14,106	15,054
Senegal	SEN	Enquête Harmonisée sur le Conditions de Vie des Ménages	2021	2022	17,435	7,129
Sierra Leone	SLE	Integrated Household Survey	2018	2018	7,555	6,840
South Africa	ZAF	Living Conditions Survey	2014	2015	56,069	23,154
Sri Lanka	LKA	Household Income and Expenditure Survey	2019	2019	22,411	19,911
Suriname	SUR	Survey of Living Conditions	2016	2017	591	2,033
Tajikistan	TJK	Living Standards Survey	2009	2009	7,490	1,503
Tanzania	TZA	National Panel Survey 2019-2020 - Extended Panel with Sex Disaggregated Data	2019	2020	60,051	1,184
Timor-Leste	TLS	Survey of Living Standards 2007 and Extension 2008	2007	2008	1,019	4,477
Togo	TGO	Enquête Harmonisée sur le Conditions de Vie des Ménages	2021	2022	8,983	6,372
Tokelau	TKL	Household Income and Expenditure Survey	2015	2016	2	119
Tonga	TON	Household Income and Expenditure Survey	2021	2021	105	2,129
Tunisia	TUN	Enquête Nationale sur le Budget, la Consommation et le Niveau de vie des ménages	2010	2011	10,825	4,854
Tuvalu	TUV	Household Income and Expenditure Survey	2015	2016	11	693
Uganda	UGA	National Panel Survey (UNPS)	2019	2020	43,737	3,059

Table S2 | Sample composition

Variables	Required information	Countries included (non-missing)	Countries excluded	Included with zero assignment	Notes
All surveys	Any eligible household survey	57	None	None	Full country sample
Fresh fish consumption	Fresh fish item surveyed or defensible zero assignment	55 (54)	Namibia, India	Ethiopia	Zero assigned where for global analyses category missing and national consumption judged negligible
Dried/smoked fish consumption	Dried/smoked fish item surveyed or defensible zero assignment	55 (47)	Namibia, India	Ethiopia, Kiribati, Marshall Islands, Tonga, Tokelau, Colombia, Cook Islands, Argentina	Zero assigned where for global analyses category missing and national consumption judged negligible
Tinned fish consumption	Tinned fish item surveyed or defensible zero assignment	53 (49)	Namibia, India, Myanmar, Cambodia	Ethiopia, Malawi, Tanzania, Uganda	Zero assigned where for global analyses category missing and national consumption judged negligible
ADM1 maps	Matched ADM1 names	49	Cook Islands, Costa Rica, Guatemala, Kiribati, Marshall Islands, Tokelau, Tunisia, Tuvalu	None	Excluded where regions were numeric codes, did not match ADM1 names, or territories where too small to display visually
Proximity to coast	Matched ADM1 names	49(global) 36(country)	Cook Islands, Costa Rica, Guatemala, Kiribati, Marshall Islands, Tokelau, Tunisia, Tuvalu	None	Global analyses retain landlocked countries, country panels required being coastal
Proximity to freshwater	Matched ADM1 names, any major domestic freshwater resource	40	Barbados, Gambia, Guinea-Bissau, Jamaica, Maldives, Timor-Leste, Tonga + no freshwater	None	Countries without qualifying domestic freshwater resources were dropped
Consumption-expenditure	Aggregate household consumption expenditure	57		None	
Dietary diversity	Sufficiently disaggregated food item data	53(MDD-W) 57(HDDS)	MDD-W: El Salvador, Jamaica, Namibia, Tajikistan	None	Vegetables for four countries too aggregated to be assigned into MDD-W categories
Food expenditure shares	Comparable food item expenditure data	49	Armenia, Barbados, Mongolia, Namibia, Nigeria, Suriname, Tajikistan, Tunisia	Individual food groups assigned to zeros if negligible as before	

Table S3 | Figure sample composition

Figure	Required information	Countries included	Countries excluded	Sample	Notes
Fig. 1A	Matched ADM1 names, sufficient visibility on map	49	Cook Islands, Costa Rica, Guatemala, Kiribati, Marshall Islands, Tokelau, Tunisia, Tuvalu	1,227,787	
Fig. 1B	Matched ADM1 names, data on both fresh and dried fish for comparability	47	Cook Islands, Costa Rica, Guatemala, India, Kiribati, Marshall Islands, Namibia, Tokelau, Tunisia, Tuvalu	958,091	Zero assignments to dried fish as specified in 'Materials and Methods'
Fig. 1C	Matched ADM1 names, any qualifying domestic freshwater resource, data on both fresh and dried fish for comparability	40	Barbados, Cook Islands, Costa Rica, Gambia, Guatemala, Guinea-Bissau, India, Jamaica, Kiribati, Maldives, Marshall Islands, Namibia, Timor-Leste, Tokelau, Tonga, Tunisia, Tuvalu	923,641	Zero assignments to dried fish as specified in 'Materials and Methods'
Fig. 2A	Aggregated household consumption expenditure, households with per capita per day values below US$ 3.00, comparable food groups	57	None	161,665	India is excluded from fish processing types because the data does not provide sufficiently detailed information. Myanmar and Cambodia do not survey tinned fish but cannot reasonably be assigned zero.
Fig. 2B	Aggregated household consumption expenditure	56	Namibia	1,258,120	Restricted to households between $0.50 and $100 per person per day.
Fig. 2C	Aggregated household consumption expenditure	56	Namibia	1,258,120	
Fig. 2D	Aggregated household consumption expenditure, MDD-W score	53	Namibia, El Salvador, Jamaica, Tajikistan	1,237,265	Restricted to households between $0.50 and $100 per person per day.
Fig. 3	Aggregated household consumption expenditure	55	Namibia, Tokelau	1,258,001	Tokelau dropped due to small sample size (n=119) and large confidence intervals.
Fig. 4A	Food budget shares, aggregated household consumption expenditure, households with per capita per day values below US$ 3.00, comparable food groups	49	Namibia, Armenia, Barbados, Mongolia, Nigeria, Suriname, Tajikistan, Tunisia	151,517	India is excluded because the data does not distinguish fish processing types (fresh vs. dried vs. tinned). Myanmar and Cambodia do not survey tinned fish but cannot reasonably be assigned zero.
Fig. 4B	Food budget shares, aggregated household consumption expenditure	49	Namibia, Armenia, Barbados, Mongolia, Nigeria, Suriname, Tajikistan, Tunisia	1,179,371	

9. Supplementary methods

9.1 Geographical harmonization

Household geographic information in HCES is typically limited. Although some surveys, mainly in Africa, include adjusted village coordinates, all surveys identify households at the first administrative level (ADM1), and many also report the second administrative level (ADM2). Surveys are generally not designed to be representative at ADM2, but these identifiers allow household data to be linked to regional geospatial measures.

We harmonized survey-reported administrative units with administrative boundary shapefiles to map survey data and link households to geospatial covariates. This required extensive text matching and manual validation because administrative names often differ across survey files and shapefiles because of spelling, transliteration, language, or administrative boundary changes. The Global Administrative Areas database (1) was used as the primary boundary source. Where GADM boundaries or names were outdated or poorly aligned with survey identifiers, we used shapefiles from the Humanitarian Data Exchange or AidData.

9.2 Adjusted consumption gradients

In addition to unadjusted consumption prevalences, we estimated country-specific adjusted associations between household welfare and food-group consumption. These models assess whether the consumption gradients observed in the descriptive analyses persist after accounting for systematic differences in household characteristics, month of interview, and subnational location. Consumption was modeled as a binary indicator equal to one if household h consumed food group g during the survey reference period. Food groups included aquatic foods; fresh, dried, and tinned fish where available; beef; poultry; goat/sheep meat; pork; dairy products; and eggs.

For each country and food group, we estimated survey-weighted logistic regressions of the form:

$$Pr\left(Y_{h,r,m}^{(g)} = 1\right) = \mathbf{\Lambda}\left(\beta_0 + \beta_1 ln\left(\boldsymbol{E}_h\right) + \beta_4 \mathbf{X}_h + \theta_r + \delta_m + \epsilon_{h,r,m}^{(g)}\right), (1)$$

where $Y^{(g)}_{h,r,m}$ indicates consumption of food group g by household h in ADM1 region r and interview month m, $\Lambda(\cdot)$ is the logistic cumulative distribution function, and $\ln(E_h)$ is per capita household consumption expenditure. X_h includes household size, household-head age and sex, urban residence, household education, and whether any household member was engaged in agriculture. ADM1 fixed effects θ_r account for persistent subnational differences in agroecology, infrastructure, market access, and local food systems. Interview-month fixed effects δ_m account for seasonality in food availability, prices, and household resources.

We report average marginal effects of log per capita consumption expenditure from these models (Fig. S22–23). Coefficients are expressed as percentage-point changes in the probability of consuming a given food group associated with a one-unit increase in log per capita consumption expenditure.

Because consumption may vary nonlinearly across the welfare distribution, we also estimated models using national consumption-expenditure deciles:

$$\Pr\left(Y^{(g)}_{h,r,m} = 1\right) = \Lambda\left(\alpha_0 + \sum_{d=2}^{10} \alpha_d D_{hd} + \gamma' X_h + \theta_r + \delta_m + \epsilon^{(g)}_{h,r,m}\right), \quad (2)$$

where D_{hd} indicates household h's consumption-expenditure decile within its national survey. We used model-based predictive margins to estimate adjusted consumption prevalence in each decile and then calculated adjacent-decile changes to show where along the welfare distribution consumption changes most strongly.

Covariate availability varied across surveys. When interview month was unavailable, but interview quarter was observed, as in Argentina, India, and The Gambia, we assigned the midpoint month of the quarter. Surveys without interview-month information were assigned a common missing-month category (Angola, Bhutan, Brazil, Ethiopia, Kiribati, Madagascar, Maldives, Rwanda, Sri Lanka, Tanzania and Tokelau). Missing household-head age in the Cook Islands, missing rural-urban location in several surveys, and missing agricultural-occupation information in Iraq, Georgia, Sierra Leone, and South Africa were handled with fixed categories to retain these surveys in the adjusted analyses. The Marshall Islands was assigned a single administrative-region category due to convergence issues. Tokelau was excluded from the adjusted gradient models because its small sample produced convergence problems.

These adjusted estimates are conditional associations, not causal effects of changes in household welfare. The models are intended to describe how consumption-welfare gradients differ across food groups and across the welfare distribution after accounting for observed household, seasonal, and regional differences.

9.3 Adjusted expenditure share gradients

We also estimated adjusted expenditure-share gradients using the same covariates and fixed effects as in the adjusted consumption models in equations (1) and (2). Because expenditure shares are continuous percentage-point outcomes, we used survey-weighted ordinary least squares regressions instead of logistic regressions. Coefficients are interpreted as percentage-point changes in a food group's share of total food expenditure associated with a one-unit increase in log per capita consumption expenditure. As in the consumption analyses, these estimates describe conditional associations and should not be interpreted as causal effects of household welfare.

9.4 Temporal gradients

To examine changes in aquatic food welfare gradients over time, we used repeated nationally representative cross-sectional surveys for countries with comparable data spanning at least five years. Where more than five waves were available, we selected up to five waves that were approximately evenly spaced. We ranked households into survey-specific consumption-expenditure deciles and plotted weighted aquatic food consumption prevalence by decile and survey wave (Fig. S26). These analyses were used to assess whether gradients were stable, steepened, or flattened over time. Survey sources for this analysis were: Armenia Integrated Living Conditions Survey (2004, 2008, 2011, 2015, 2018), Kenya Integrated Household Budget Survey (2005/06, 2015/16), Ethiopia Socioeconomic Survey (2015/16, 2018/19, 2021/22), Tanzania National Panel Survey (2008/09, 2010/11, 2012/13, 2014/15, 2019/20), Niger National Survey on Household Living Conditions and Agriculture (2011, 2014/15), Enquête Harmonisée sur le Conditions de Vie des Ménages (2018/19, 2021/22), Mali Enquête Agricole de Conjoncture Intégrée (2014), Mali Enquête Harmonisée sur le Conditions de Vie des Ménages (2018/19, 2021/22), Sierra Leone Integrated Household Survey (2011, 2018), Ghana Living Standard Survey (2005/06, 2012/13, 2016/17), Rwanda Integrated Household Living Conditions Survey (2010/11, 2013/14, 2016/17, 2023/24), Nigeria General Household Survey (2010/11, 2012/13, 2015/16), Nigeria Living Standards Survey (2018/19), Malawi

Integrated Household Survey (2004/05, 2010/11, 2012/13, 2016/17, 2019/20), Georgia Households Incomes and Expenditures Survey (2009, 2013, 2016, 2020, 2023), Democratic Republic of the Congo National Household Survey (2004/2005, 2012/13).

9.5 Gradients and food prices

To assess whether cross-country variation in aquatic food welfare gradients was related to national food prices, we linked country-specific adjusted consumption gradients to International Comparison Program price-level indices. Gradients were estimated from the household-level survey-weighted logistic models and represent percentage-point changes in the probability of consuming a food group associated with a one-unit increase in log per capita consumption expenditure.

We used ICP price-level indices for fish and seafood and for meat. The relative fish/meat price was defined as the fish and seafood price-level index divided by the meat price-level index. To avoid mixing ICP benchmark years, the main supplementary plots used 2017 ICP prices for all countries. Price variables were standardized to have mean zero and unit variance.

We estimated three descriptive cross-country associations: the adjusted aquatic food gradient against the fish and seafood price level; the adjusted aquatic food gradient against the relative fish/meat price; and the difference between the adjusted aquatic food and average terrestrial-meat gradients against the relative fish/meat price. Positive values of the gradient difference indicate that aquatic food consumption is more concentrated among higher-expenditure households than terrestrial-meat consumption.

Regressions were estimated across country surveys. Preferred specifications weighted countries by the inverse variance of the estimated aquatic food gradient. For gradient-difference outcomes, weights used the combined variance of the two estimated gradients. We also estimated unweighted regressions, models using log-transformed price variables, and alternative comparisons replacing the average terrestrial-meat gradient with beef and poultry gradients separately. These analyses are descriptive and should not be interpreted as causal effects of prices.

9.6 Survey-specific data decisions and exceptions

Recall periods. Most surveys used either a 7-d consumption recall or a food diary. Exceptions included Ghana, which used a 5-d reference period, and Tokelau, which used a 14-d reference period. In India, cereals, cereal substitutes, and pulses were collected over a 30-d reference period, whereas other foods, including aquatic foods, were collected over a 7-d reference period.

Food items detail. Food item detail varied across surveys. Namibia reported only aggregate animal-source food categories and was therefore excluded from analyses comparing aquatic foods with specific terrestrial meat categories or fish processing types. India did not distinguish aquatic foods by processing type and was excluded only from processing-type analyses, while remaining in analyses of aggregate aquatic foods and terrestrial meats. Myanmar and Cambodia did not include a separate tinned-fish category and were excluded from tinned-fish analyses. For a small number of food categories not explicitly surveyed, non-collection was likely due to negligible consumption in that setting. For pooled analyses, these categories were coded as zero if the national consumption share of that processing category was below 5% using FAO FishStat data. This applied to dried fish in Argentina, Cook Islands, Colombia, Ethiopia, Kiribati, Marshall Islands, Tonga, and Tokelau; tinned fish in Ethiopia, Malawi, Tanzania, and Uganda; pork in Ethiopia, Maldives, and Iraq; and goat/sheep meat in Cambodia, El Salvador, and Costa Rica.

Expenditure share analyses. Expenditure-share analyses required both household consumption aggregates and comparable food-group expenditure data. We therefore excluded surveys without consumption expenditure aggregates, without disaggregated animal-source food categories, or without comparable food-group expenditure measures. This excluded Namibia, Armenia, Barbados, Nigeria, Suriname, Tajikistan, and Tunisia from expenditure-share analyses.

9.7 Sensitivity analyses

Measures of income or welfare gradients. We first use a logarithmized continuous measure of household consumption expenditure to proxy income or economic welfare. In addition, we used consumption-expenditure deciles to summarize distributional differences (S20–21, S24–26). Deciles provide a rank-based measure of relative welfare, with households grouped into ten equally sized population groups within each national survey. This measure is less sensitive to extreme values and facilitates transparent comparisons between households at different positions in the welfare distribution, such as the poorest and richest deciles. Continuous log expenditure was used to estimate gradients and nonlinear relationships, whereas deciles were used to present distributional contrasts.

Adjusted geographic exposure to marine and freshwater resources. As sensitivity analyses, we estimated adjusted associations with ADM1-level weighted linear probability models (Fig. S8). For each outcome, we regressed ADM1 mean consumption on quadratic terms for the exposure of interest and the alternate water-resource exposure, controlling for country fixed effects and ADM1-level covariates: mean household size, urban share, agricultural-occupation share, survey month, log per capita consumption expenditure, and missingness indicators where relevant. ADM1 observations were weighted by represented household population, and standard errors were clustered by country. Predicted values were calculated over the observed exposure range while holding the alternate water-resource exposure at its weighted sample mean. In addition to quadratic distance terms, we estimated binned exposure indicators (Fig. S9).

Finer geographic exposure to marine and freshwater resources. One limitation of our approach is that it assigns a single exposure value to all households in the same administrative unit and therefore cannot capture within-region heterogeneity. To assess whether finer granularity changes the results, we repeated the analyses using ADM2 exposure measures for countries with named ADM2 regions (Fig. S12–14). The ADM2 analyses used the same household sample wherever possible and compared results based on ADM1 versus ADM2 exposure assignment. The results were broadly similar, although the ADM2 analysis suggests that ADM1 regions may be too coarse to capture local exposure to major freshwater resources in some settings.

10. SI References

1. GADM, Database of Global Administrative Areas. Deposited 2023.