Global hidden harvest of freshwater fish revealed by household surveys

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Consumption of wild-caught freshwater fish is concentrated in low-income countries, where it makes a critical contribution to food security and livelihoods. Underestimation of inland harvests in official statistics has long been suspected due to unmonitored subsistence fisheries. To overcome the lack of data from extensive small-scale harvests, we used household consumption surveys to estimate freshwater fish catches in 42 low- and middle-income countries between 1997 and 2014. After accounting for trade and aquaculture, these countries collectively consumed 3.6 MT (CI, 1.5–5.8) more wild-caught freshwater fish than officially reported, reflecting a net underreporting of 64.8% (CI, 27.1–103.9%). Individual countries were more likely to underestimate (*n* = 31) than overestimate (*n* = 11) catches, despite conservative assumptions in our calculations. Extrapolating our findings suggests that the global inland catch reported as 10.3 MT in 2008 was more likely 16.6 MT (CI, 2.3–30.9), which accords with recent independent predictions for rivers and lakes. In human terms, these hidden harvests are equivalent to the total animal protein consumption of 36.9 (CI, 30.8–43.4) million people, including many who rely upon wild fish to achieve even minimal protein intake. The widespread underreporting uncovered by household consumption surveys indicates that inland fisheries contribute far more to global food security than has been recognized previously. Our findings also amplify concerns about the sustainability of intensive fishery exploitation as degradation of rivers, lakes, and wetlands continues apace.

inland fisheries | capture fisheries | consumption surveys | national statistics | food security

Freshwater capture fisheries account for only 7% of reported global fish harvests (1), yet these harvests are concentrated in low-income countries where their essential contributions to food security and rural economies are widely underappreciated (2, 3). Official statistics from the United Nations Food and Agriculture Organization (FAO) indicate continuous year-over-year increases in global inland catches—a net doubling over the last 28 y—which contrasts with stable (1) or declining marine catches (4). Widespread accounts of reduced abundance and size of fishes caught from rivers and lakes, as well as changes in the species composition of harvests, suggest declining stocks due to overfishing and environmental degradation (5). The seeming contradiction between rising global freshwater catches and signs of local overharvest may be attributable to increases in fishing effort and supplementation of wild fisheries by stocking (6). In addition to actual increases in harvest, growth in reported catches may reflect improvements in the catch statistics reported voluntarily by individual countries to the FAO (7, 8). A reliable baseline quantification of inland catches is requisite to evaluating the status and trends of freshwater fish stocks, and ensuring their continued contribution to food security through sustainable harvests (9, 10).

Underestimation of global inland fisheries has long been suspected due to incomplete or ineffective monitoring of artisanal and subsistence harvests (11). Surveys of landing sites, fishing effort, or fish markets form the basis for most reported catch statistics (7). These approaches invariably exclude or underrepresent geographically dispersed, small-scale fisheries whose catch is consumed without entering market chains (3, 8). Countries without fishery monitoring systems generate their statistics using proxy variables or simply do not report inland catches (7, 12). Missing or erroneous catch statistics are approximated by FAO from other available information in the interest of presenting comprehensive statistics (6, 12, 13). Unfortunately, underestimation of inland fisheries undermines their standing in decisions about economic development, food security, and natural resource management, as well as creates little incentive to improve data collection (8, 11). Alternative assessment approaches are needed to adequately portray the magnitude of inland harvests and their importance for human nutrition and livelihoods (14).

Fish consumption recorded by household consumption and expenditure surveys (HCESs) offers a promising means of assessing catches even where direct monitoring of fisheries is limited (15–17). These surveys are administered by national authorities and can estimate per capita daily consumption of fish products within individual households over recall periods of up to 2 wk (18). Surveying large numbers of households can represent geographically dispersed fisheries more effectively than periodic monitoring of particular landing sites or markets (11, 15, 17). However, to estimate the original harvest levels, consumption of freshwater fish products recorded in HCESs must be disaggregated from marine, aquaculture, and trade sources, and adjusted to reflect biomass discarded during preparation of whole fish for consumption (15). The promise of HCESs is exemplified by analyses in the Lower Mekong Basin—the world's largest inland fishery—where catch estimated from household consumption surveys revealed twice as much catch as reported in official statistics (16, 19). HCESs also revealed the extent of traditional fishing operations in the middle and upper Amazon

Significance

Experts have long believed that fish catches from rivers and lakes are underreported, which leads to lack of appreciation for their contribution to global food security. Rather than focusing on landing data, we backcalculated harvests using surveys of household consumption of freshwater fish. Data from 548,000 households across 42 countries reveal that freshwater catches are likely to be ~65% higher than officially reported. These hidden harvests are concentrated in low-income countries where they represent the equivalent of the total annual animal protein consumption of 36.9 million people. Long-term underreporting of inland fisheries masks their critical role in feeding the world's poor and complicates using catch statistics to evaluate the impact of overharvest and ecosystem degradation.

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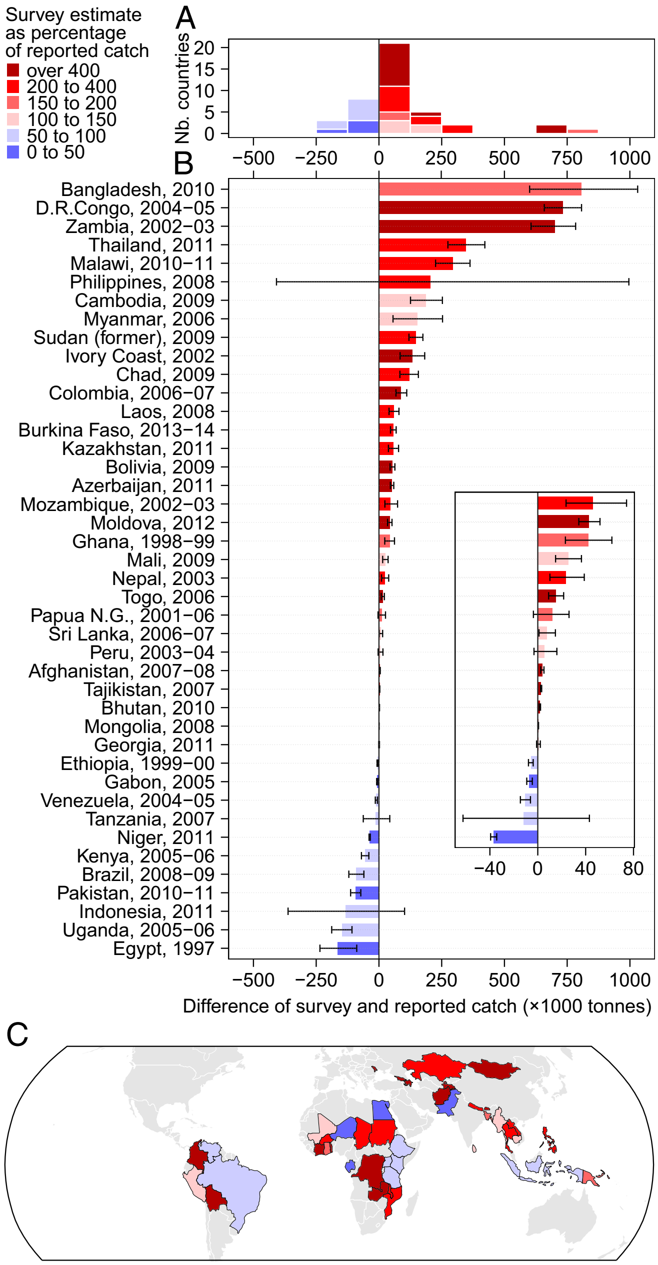

Fig. 1. (*A*) The distribution of tonnage difference in 42-country sample is concentrated within 0- to 125-kT interval, which represents a large relative departure from reported statistics (twofold and greater) for many countries in the interval. (*B*) Survey countries ordered by absolute tonnage difference between reported catch statistics and HCES estimates. Reading from *Top* to *Bottom*, most of the countries (n = 31) have larger household survey estimates indicated by a positive value, while the remaining countries (n = 11) have greater reported catch represented by negative values. The *Inset* box magnifies the axis for countries with small tonnage differences (Gabon to Mozambique). Error bars represent the 95% uncertainty interval around the survey-estimated catch. The color of each bar reflects the relative difference between survey-estimated catch and reported catch statistics expressed as the percentage ratio of survey over reported. (*C*) Survey catch greater and lower than reported catch are found in every continent, indicating that underreporting is not a geographically restricted issue.

basin (20). To date, fish catches have not been estimated via the HCES approach for most regions of the world, let alone synthesized to estimate global harvests of freshwater fish.

In this paper, we analyze the magnitude of underreporting of inland fisheries using HCES data from 548,433 households in 42 countries. These low- and middle-income countries are distributed across South America, Europe, Africa, and Asia. They accounted for 53.2% of reported global inland catch in 2008 and included 23 of the 31 largest reported national catches (1). Between 1997 and 2014, authorities in each country surveyed fish consumption (*SI Appendix*, Fig. S1*A*) in a spatially stratified subset of households during a single year [0.44 ± 0.55% (mean ± SD) of national population; *SI Appendix*, Table S1]. Inland capture fisheries contribute significantly to livelihoods and food security in the surveyed regions (3), but individual nations vary widely in their reliance on aquaculture, trade, and marine harvests as additional sources of fish. We estimated inland catch from consumption surveys by excluding fish from marine harvests, converting processed weight to live weight equivalents, and subtracting supplies of freshwater fish from aquaculture and trade. We then compared HCES-based fish harvests to inland catch statistics reported by FAO from the same years to reveal the magnitude of underreporting and estimate the contribution of hidden harvests to food security.

Results and Discussion

Household surveys indicated an inland catch of 9.26 MT (CI, 7.12–11.42 MT) across these 42 nations. Reported catches from the same year as each survey sum to only 5.60 MT. The implied aggregate underreporting of 64.8% (CI, 27–104%) based on HCES is consistent with previous in-depth assessments of landings for a subset of countries (averaging 70% underreporting; ref. 2).

Individual countries showed both positive [n = 31; total of 4.38 MT (CI, 2.74–6.06)] and negative [n = 11; total of 0.74 MT (CI, 0.24–1.22)] differences between HCES-based catches and official statistics (Fig. 1*A*). The difference in aggregate catch tonnage is primarily driven by Bangladesh, Democratic Republic of Congo, and Zambia, which collectively contribute a surplus of 2.23 MT, or 42% (CI, 36–52%) of total hidden harvests estimated for the 42 surveyed countries (Fig. 1*B*). Both positive and negative deviations were found among nations on each continent (Fig. 1*C*). Only nine countries showed close agreement (within 10 kT) between HCES-based and reported catches. Disparities were sufficiently common across our sample of nations to yield significant overall underreporting (Wilcoxon paired signed-rank test; $P < 0.005$) even though the rank order of countries remained correlated between HCES-based and reported catch estimates (Kendall $\tau_b = 0.64$; $P < 0.001$).

Country-level differences are even more striking when expressed in proportion to reported catch. Survey-estimated catch was more than twofold higher than reported catch in 22 of 42 countries analyzed, and more than fourfold greater than reported in nearly one-third of countries (n = 13). Some of the starkest relative disparities were in small, low-harvest countries like Bhutan, Moldova, and Azerbaijan, as well as in Democratic Republic of Congo, Zambia, and Malawi, which have major recognized fisheries yet substantially underreport in both absolute and relative terms. Agreement to within ±20% of reported catch was found in only three countries, while 12 were within ±50%.

Differences between HCES-based and FAO-reported catches are usually unequivocal; reported harvests fell outside the CI of HCES for 36 of 42 countries despite large uncertainty ranges (95% CI width is 76% of estimated catch, on average). Similarly, the aggregate HCES-based catch significantly exceeds the sum of reported catches from the same years. Whereas no quantitative uncertainty metrics are available for FAO's inland harvest statistics, we computed CIs for HCES-estimated catches using Monte Carlo simulations of the uncertainty about the provenance (marine vs. inland) of unidentified fish products and estimation of the fresh weight lost from preparation and preservation prior for consumption. The uncertainty of the aggregate HCES catch derives primarily from the fish preparation rather than its provenance (81% and 19% of CI, respectively), but the contribution of each varies among countries (*SI Appendix*, Fig. S2).

Our HCES-based catch estimates can be considered robust minima given the conservative assumptions we used in interpreting

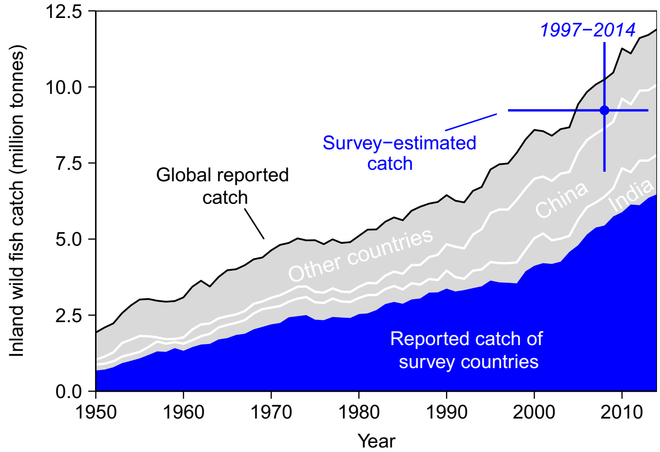

Fig. 2. Global increase in inland fish catch according to reported statistics (black line). The reported catch for the 42 countries with HCES (blue area) has seen a rapid growth during the past decades but has yet to match the survey-estimated catch [blue cross representing the mean HCES catch and 95% CI across the time period covered by surveys (1997–2014)]. China and India account for most of the reported catch in countries not analyzed with HCES.

survey data. For instance, we assumed that a fraction of unidentifiable fish was marine-derived even in landlocked nations [maximum inland fraction is 78% (CI, 65–91%); *SI Appendix*, Figs. S1*B* and S3]. We also assumed that household fish consumption was indicated in fresh weight units rather than smoked or dried (unless specified otherwise), thereby yielding minimum estimates of the original harvested biomass (*SI Appendix*, Figs. S1*C* and S4). The degree of reliance on these assumptions depended on the description of fish products listed in surveys and varied among nations. In addition to our conservative assumptions during data processing, HCES data are known to underestimate fish consumption due to recall error by respondents (16) and by excluding fish consumed outside the home (21). Seasonality of fishing efforts and fish accessibility could also have introduced error into HCES-based estimates, but that uncertainty should have had no systematic bias across countries (15).

Aside from hidden harvests, the discrepancies between HCES-estimated and reported catch could be affected by the accuracy of the reported trade and aquaculture production on which our calculations rely. Like statistics on inland fish catch, aquaculture and trade statistics are submitted by national governments to FAO without quantitative uncertainty metrics (7, 12). Aquaculture production is likely to be more accurately documented than inland capture fisheries given its controlled production may facilitate recordkeeping, although aquaculture statistics may be inflated through the inclusion of stocked natural water bodies as cultured production (7). Our conclusions are unaffected by potential misattributions between wild fisheries and aquaculture, as wrongly attributed production would cause offsetting errors in the HCES-based and reported catches that would nullify each other when calculating differences. In addition, trade of wild-caught freshwater fish across national borders is generally considered low with the exception of some particularly productive fisheries (e.g., Mekong River Basin, African Great Lakes; refs. 3 and 8), leading trade statistics to focus primarily on aquaculture and marine fisheries. Nonetheless, informal overland trade of dried freshwater fish can be substantial in sub-Saharan Africa despite being overlooked in official statistics (22, 23). For instance, regional analyses indicate 48 kT of annual exports from Zambia to Democratic Republic of Congo (24) and 100 kT per year from Lake Chad to Nigeria (25). In each case, these trade fluxes are approximately equivalent to the entire reported freshwater catch for these countries. While unreported trade of inland fish is no less plausible than uncounted harvests in countries with low monitoring capacity, the HCES approach to catch estimation is robust to trade at a regional scale because erroneous import and export records from different countries should offset each other on aggregate. Overall, estimates of inland catches from household consumption surveys are considered most reliable in countries with minimal trade, aquaculture, and marine fisheries.

In addition to the calculations reported above for 42 nations, we excluded results from HCES in seven other countries, including some of the largest producers of inland capture fisheries (i.e., China, India, Vietnam) that together accounted for 34% of global FAO-reported catch in 2008. Although HCES data from these nations confirm their high reliance on freshwater fish, each of them reports substantial production from aquaculture, much greater than their wild catch, yielding negative HCES-based production estimates after correcting consumption of inland fish for aquaculture and trade sources. Either overreporting of aquaculture production or underreporting of export of cultured fish could have caused the negative wild-capture estimates in the excluded countries (8). The same types of inaccuracies could also have introduced a negative bias in other countries where HCES-based catch estimates were positive yet substantially lower than expected (e.g., Pakistan, Brazil, Indonesia). Diagnosing problems with aquaculture or trade statistics was beyond the scope of this study; therefore, we excluded these seven nations from our HCES calculations despite their major freshwater harvests. Indeed, the dependence of HCES-based calculations on trade and aquaculture statistics provides additional impetus for improving those data.

Further analysis of the statistical correlates of differences between HCES-based and FAO-reported catches suggests that inferred patterns of underreporting are more consistent with the existence of hidden fish harvests than deficiencies in FAO statistics. We tested two separate sets of predictors: sociogeographic indicators from the World Bank (26) that might be associated with the prevalence of small-scale fisheries difficult to monitor [i.e., surface water density, rural population density, gross domestic product (GDP) per capita, etc.; *SI Appendix*, Fig. S5], and FAO's indicators of potential inaccuracies in the aquaculture and trade statistics used to calculate HCES-based catches (i.e., quality-control flags that indicate gaps in the data reported by nations, instead estimated by FAO). Using a model selection approach, we found that sociogeographic predictors explained more of the variance than indicators of data quality [generalized linear model (GLM); log-link; Cox–Snell pseudo-R^2 = 0.61 and 0.47; bias-corrected Akaike information criterion (AICc) = 553.2 and 560.5, respectively; *SI Appendix*, Fig. S5]. Model averaging suggests that the most important sociogeographic predictors were rural population density and its interaction with other predictors, suggesting that the widely dispersed demand for fish may exceed the capacity of national governments to accurately monitor or estimate landings (see also ref. 6). Our model comparisons excluded data quality flags for inland catch statistics themselves to avoid circularity in interpretation, but experimentally adding catch flags enhanced the explanatory power of the model (Cox–Snell pseudo-R^2 = 0.65; AICc = 551.1; *SI Appendix*, Fig. S5), thereby further supporting the hidden harvest interpretation. Indeed, the positive regression coefficient for catch flags suggests that the approximation of missing catch statistics by FAO is systematically overconservative; 9 of 10 countries with flagged catch statistics were underreporting catch according to our HCES-based calculations. When we included both sociogeographic and data quality predictors, the complementary information from these sets of predictors substantially increased explanatory power (GLM; log-link; Cox–Snell pseudo-R^2 = 0.90; AICc = 522.3; *SI Appendix*, Fig. S5).

Our set of countries with HCES-based catch estimates is sufficiently representative to allow exploratory extrapolations of the global magnitude of inland catches. The full model described above (including both sociogeographic and data quality predictors) was applied to 38 additional countries within the range of GDP per capita encompassed by the 42 nations whose HCESs we analyzed. This approach predicts the relative underreporting of HCES-based catch, which can be applied to the FAO-reported

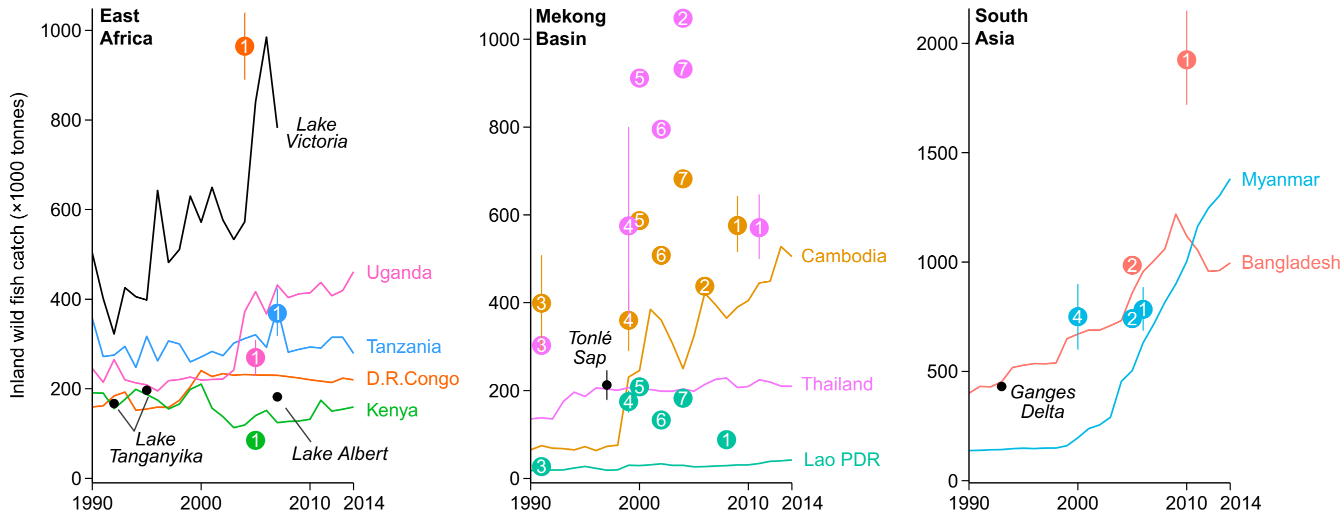

Fig. 3. Timeline of reported inland catch statistics collected by FAO, shown alongside independent catch estimates with matching country colors and numbered by source (1, this study; for 2–7, see *SI Appendix*, Table S2). Catch estimates for water bodies with significant fisheries are depicted as black lines or points. (*Left*) The survey-estimated catch is lower than reported statistics in the three riparian countries of Lake Victoria and is interpreted as a combination of suitable monitoring in reported statistics and conservative survey estimates. (*Center*) Numerous estimates for countries of the Mekong River Basin provide the best available evidence historically underreported catch. (*Right*) Both Myanmar and Bangladesh have doubled in reported catch during the last decades. Myanmar has reported a systematic, possibly institutionalized, annual catch increase that has surpassed the catch estimates of ∼750 kT made between 2002 and 2006 (15).

catch to produce an inferred catch for each country (*SI Appendix*). The extrapolation brought the total coverage to 80 countries that accounted for 93.4% of reported global catch in 2008. The inferred catches from China and India, the two largest producer countries in our extrapolations, were partially offsetting; China's inferred catch is lower than reported by 1.9 MT (which may reflect confounding of stocked wild fisheries and aquaculture; ref. 6), while India's inferred catch is 2.5 MT greater than reported. The net difference between inferred catches and FAO-reported catches for these 38 nations sums to 0.77 MT of additional underreporting. Relying on reported catches from the remaining 59 countries of the world, we estimate total global capture of wild freshwater fishes as 16.6 MT (CI, 2.3–30.9) in 2008, compared with reported catch statistics of 10.3 MT. This degree of global underestimation (63%) matches our findings from the 42 HCES countries (65%) and is certainly conservative because it relies on reported statistics for many countries where recreational fish harvest is substantially underreported (7, 27).

The widespread underreporting revealed by household consumption surveys raises questions about the reliability and interpretation of ostensible increases in reported global inland catches over the last six decades (Fig. 2). That sustained rise could reflect actual increases in harvest against a backdrop of consistent underreporting, or instead represent steady improvements in reporting with stagnation or even decline in actual catch (8). To date, the lack of a consistent, large-scale alternative to FAO's statistics has made it impossible to distinguish true increases in catch at monitored landing sites from improvements in reporting such as the inclusion of additional fishing sites or reclassification of some production as aquaculture (28). Countries where multiple independent catch estimates indicate higher catch than reported, such as in South and Southeast Asia (Fig. 3), provide the best available indications of historic underreporting (16, 19), but a reliable trend through time cannot be drawn from these occasional independent estimates. Nonetheless, large single-year adjustments in catches (>30% year-over-year difference) reported by individual nations are collectively responsible for 53% of the total increase in FAO-reported catches since 1950, eliciting suspicion about the role of reporting improvements in the overall pattern (13). Although FAO strives for continual improvement of the national statistics that it compiles, we infer that the hidden harvests revealed by household surveys are probably present even in the most recent data based on a lack of correlation between the magnitude of underreporting (or overreporting) indicated by HCESs and the change in FAO-reported catches in the years since each survey was conducted (GLM log-link; $P > 0.2$; Cox–Snell pseudo-R^2, 0.03). Given the juxtaposition of gradual improvement in catch reporting for some nations (28) with the underreporting documented herein, we believe that long-term trends in FAO-reported catches should not be construed as compelling evidence of increasing catches through time nor used as indicators of further exploitation potential or response to ecosystem stressors (3, 6).

Improving the reliability of inland fishery statistics should be pursued with multiple complementary approaches that enhance data quality and increase the spatial grain of assessment. For instance, repeating HCES efforts could produce catch national trends through time for comparison with those from FAO statistics. HCES data could be enhanced by inclusion of additional details of taxonomic identity, ecosystem provenance, and preparation methods, enabling future work to sidestep some of the key assumptions necessary for our calculations. To address the long-term prospects of inland fisheries, we also need systematic data on cultural, demographic, and biological factors aside from fishing pressure (3). Whereas trajectories of standardized catch, effort (29), and primary productivity (30) are widely used to infer exploitation status for particular species and locations in marine waters, none of these predictors is well monitored in most inland waters. Enhancing the spatial resolution of FAO's inland fishery data to the scale of individual river basins and lakes would also facilitate evaluation of overexploitation. Even a few dozen such sites could open the door to using waterbody-specific productivity models (6, 31, 32) and environmental stressor analyses (3) to extrapolate from well-studied sites to unmonitored fisheries.

The massive hidden harvests revealed by HCES in low-income countries correspond to a substantial underestimate of the role of inland fisheries in human food security. To evaluate the nutritional contribution of hidden harvests, we calculated the equivalent additional number of people whose total animal protein consumption would be provided by the unreported inland fish catch (Fig. 4). Based on the calculations presented in ref. 3, FAO-reported inland catches in the countries analyzed are equivalent to the total animal protein intake of 82.2 million people (CI, 65.5–96.3). After including both increases and decreases inferred from HCES, we estimate that hidden harvests feed the equivalent of 36.9 million people (CI, 30.8–43.4), raising the total dependence on inland fisheries to be

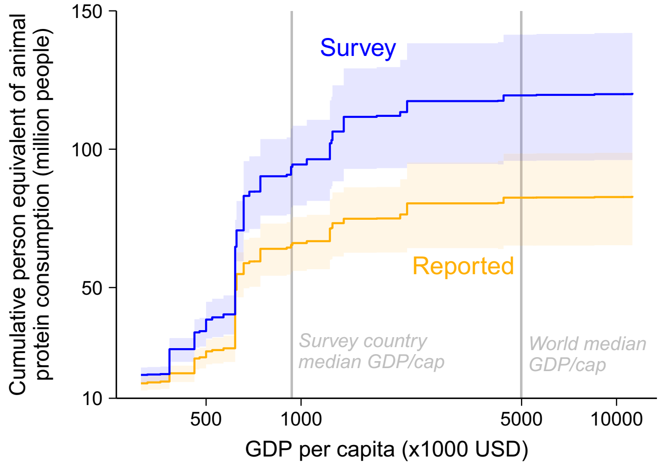

Fig. 4. Nutritional equivalence of the inland fish harvest as number of people meeting their total animal protein consumption. The hidden harvest revealed by the survey-estimated catch is equivalent to the entire animal protein intake of an additional 36.9 (CI, 30.8–43.4) million people, and most of the increase is found in countries below the median GDP per capita of countries surveyed (vertical line). The largest national increases in nutritional equivalence come from Zambia, Mali, and Tanzania. The bands represent the uncertainty from the provenance of the fish consumed (freshwater or marine) as used in the calculation of HCES catch.

equivalent to all animal protein consumed by 119.1 million people (CI, 99.4–142.7) in the 36 countries where protein consumption data were available. This major increase in the reliant population reflects the fact that hidden fish harvests are consumed primarily in countries where low dietary animal protein is the norm and alternative sources of nutrition are generally unaffordable (3). For instance, the nations with the largest proportional increases in estimated human dependence have large unrecorded catch (e.g., Democratic Republic of Congo, Myanmar) and/or very low animal protein consumption rates (e.g., Afghanistan, Burkina Faso). In both cases, it behooves national governments, international development agencies, and donors to recognize the importance of small-scale inland fisheries for food security (33) and to promote sustainable management of these fisheries (34). Notably, the nutritional value of fish as sources of essential fatty acids and micronutrients is disproportionate to their protein and caloric content (35); hence the actual role of hidden harvests in food security could be dramatically underestimated by our calculations.

In summary, our results indicate that underreporting of inland fisheries is widespread among low-income nations, and that over one-third of global inland catch goes unreported. The inaccuracy of official catch statistics suggests that long-term increases in reported global inland harvest may not be reliable. These hidden harvests from rivers and lakes have resulted in long-standing underappreciation of the contribution of inland fisheries to food security in low-income countries (35), which leads in turn to inadequate accounting for the value of freshwater fisheries in decisions about dams, irrigation, flood control (36), and other water uses (14, 37). The unreported catches from inland fisheries indicated by HCES also challenge simplistic assumptions regarding potential substitution of cultured fish for wild-caught species; the large amount of wild fish eaten by impoverished people in remote areas would be difficult to replace with aquaculture production. Thus, close attention should be paid to impacts on wild fish stocks when cultured species are raised in natural waters with the goal of increasing net fish harvests to meet regional and global demand (38). By elucidating the importance of freshwater fisheries in global food security, our findings underscore the urgency of enhancing the sustainability of current exploitation to avoid jeopardizing a key nutritional resource for the world's poor.

Methods

This section presents a description of methods, with full details provided in *SI Appendix*.

Household Surveys and Fish Provenance. HCESs were drawn from a collection assembled by FAO (18, 39) and a report on Asia–Pacific countries (40). HCESs record aquatic animals (i.e., fish, crustaceans, and mollusks) acquired by any means (i.e., caught, bartered, or purchased) by the household over a 1-d to 2-wk recall period before the interview. Fish consumption rates were summarized to units of grams·person^{-1}·day^{-1} from traditional units (e.g., heaps, tins) and inedible portions were retrieved before our analysis (ref. 18 and *SI Appendix*).

The level of detail about taxonomy and preservation of consumed fish varied widely among nations. We identified fish items of inland provenance, regardless of wild versus cultured source, through taxonomic matching and expert opinion. Euryhaline and diadromous species (e.g., hilsa, mullets) were categorized as inland for consistency with FAO reporting. For fish entries whose provenance could not be determined unambiguously (~22% of total consumption from HCES), we predicted the fraction of freshwater origin (F in Eq. **1**) of HCES countries from the fraction of apparent consumption statistics of FAO's food balance sheets (41) using GDP per capita and length of marine coastline as predictors (*SI Appendix*, Fig. S3 and *SI Appendix*). We also converted fish consumption data to units of fresh, whole weight to make them comparable to FAO-reported catch statistics. HCES data on processed weight was converted using conversion factors that account for removal of inedible parts (e.g., gutting or filleting) and dehydration during preservation (e.g., smoking, salting, freezing). Conversion factors from the literature on freshwater and diadromous fish species were compiled for uniform application in our calculations (*SI Appendix*, Fig. S4). Fresh mass units were assumed when a preservation method was not indicated. This assumption did not drive the patterns of underreporting (*SI Appendix*).

National HCES-Based Catch Calculations. We calculated total inland fish consumption (R_i) in fresh weight equivalents for each country (i) as the sum of the annual consumption (C_{ij}) of each fish product (j) weighted by its fraction of inland provenance (F_{ij}) and live-weight conversion factor (L_j):

$$R_i = \sum_{j}^{1} F_{ij} \times C_{ij} \times L_j. \quad [1]$$

This total fish consumption includes sources of fish other than capture of wild freshwater fish. Thus, we calculated HCES-based catch (S_i) of each country by adding exports (E) of inland fish to R_i, and then subtracting imports of inland fish (I) and aquaculture production (A) as follows:

$$S_i = R_i + E_i - I_i - A_i. \quad [2]$$

This approach applies the same logic used to estimate apparent consumption from reported harvest statistics (1), but sidesteps assumptions about nonfood uses obviated by consumption surveys. Each component of Eq. **2** represents a summation across species and products because the details available in national trade and aquaculture statistics do not align with the nomenclature in HCESs. Uncertainty ranges for S_i were calculated as the 2.5th and 97.5th percentiles of 10,000 Monte Carlo simulations of the R, E, and I components of Eq. **2**. In these simulated data, variation in R_i arose from random sampling from distributions of bootstrapped GAM model predictions of proportion of fish from freshwater sources (F) and fresh weight conversion factors (L). Variation in traded fish products (E and I) also arose from L, as reported statistics were converted to fresh-weight equivalents according to their reported processing with the same conversion factors used for HCES consumption.

Predictors of Underreporting. To explore the factors associated with underreporting of inland fisheries, we tested two classes of predictors of the relative difference between HCES-based and FAO-reported catches: (i) sociogeographic factors that could impede monitoring (8), and (ii) potential inaccuracy in trade and aquaculture statistics noted by FAO. Four sociogeographic factors were extracted from World Bank data for the year of each country's survey (26) and a global surface water model (42): total land surface, rural population density, percentage of land under surface water, and GDP per capita. Potential inaccuracy in reported statistics was quantified separately for harvest, import, export, and aquaculture as the percentage of tonnage flagged by FAO internally ("F" symbol) due to data quality concerns (43) in each country. To consider the effect of the quantity statistics being flagged, we included statistics of import, export, and aquaculture as a percentage value of the reported catch in each country, and considered their interaction with the flags. Both sociogeographic and data quality predictors were tested with an exhaustive subset approach to model selection using the AICc of generalized linear models with logarithmic link function implemented in the R package "glmulti" (44). Based on a breakpoint in the AICc profile, the best 23 models were averaged with the package "modEvA" (45). Models were fitted on data from 39 countries with HCES data after excluding Bhutan, Moldova, and Azerbaijan as outliers due to low reported catch and >50× apparent underreporting. The resulting averaged model demonstrated moderate accuracy in predicting relative degrees of underreporting across countries (root-mean-square error, 118.7%; *SI Appendix*, Fig. S6). In aggregate, the inland catch predicted by the underreporting model was 27% (2.5 MT) lower than the HCES-based estimate for nations used to train the model.

Person Equivalent Calculation. We estimated the additional number of people per country whose animal protein consumption could be met with hidden fish harvests in HCES nations following published methods (3). The additional dependence is calculated as the mismatch in estimates using consumption from reported statistics and from HCES fish consumption. The dependence D_i of each country i is calculated as the protein from inland fish (I_i) over the sum of the protein from all fish (F_i) and all other animal protein consumption excluding fish (O_i), and then multiplied by the country's population (N_i):

$$D_i = I_i/(F_i + O_i) \times N_i. \quad [3]$$

The dependence is calculated twice for each country using I and F from reported statistics, and then from HCES, and the difference in D_i is the additional dependence. Substitution of F_i with HCES consumption, alongside I_i, attempts to make our estimate of nutritional contribution as conservative as possible yet assume that reported O_i remains appropriate despite underreporting and overreporting of fish consumption.

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