**Reviewer Response for**

Dried fish provide widespread access to critical nutrients across sub-Saharan Africa

**Editor Comments:**

Thank you for considering PNAS for your research. We have now secured two reviews of your manuscript from experts in the field. Both suggest revisions are needed, even as they find the manuscript to be of value. We ask that you consider and address their comments and suggestions fully in a revised resubmission. We may ask for additional review of the revised manuscript after editorial review of the revisions and asking for a revised resubmission is not a guarantee of eventual publication.

## **R:** Thank you for the opportunity to revise our manuscript. We respond to each reviewer comment below, explaining where and how the manuscript was revised. On discussion between co-authors, we have also removed ‘*sub-Saharan*’ from our title and manuscript text because this term has a colonial history and is not rooted in any meaningful geographical divisions.

**Statistical and Methodological comments:**

I read the paper and analysis. The methods are generally well described and the modeling approaches for the various analyses and resulting inferences seem appropriate and valid. I took a very brief look at the data and code on the github repository, and everything seems well documented and thorough. My two complaints would be:

1) There is a lot of material on the data/code repository. A README file would be helpful to allow for full reproducibility of the results presented.

## **R:** Thank you for this suggestion. We have added a README file to the Github repository to help with reproducibility. This explains that all analyses and figures can be recreated in full.

2) It might just be my PDF reader, but the logistic regression equation (1) in the Methods sections does not render correctly.

## **R:** Apologies. We have re-formatted this equation and ensured that it does appear in Microsoft Word.

**Reviewer 1**

This paper examines the importance of dried fish for nutrition in sub-Saharan Africa,

focusing on the contribution to closing nutrient gaps, and also some of the drivers

(determinants) of dried and fresh fish consumption, as well as potential food

safety/health risks.

Overall, the paper is interesting and compelling, and I agree that there is a case to be

made that dried fish – and perhaps fish in general – are neglected in terms of their

potential to contribute to improved nutrition in sub-Saharan Africa, as well as other

regions. However, I think there is quite some room for improvement. Full disclosure: I

am not a fish expert, but an economist working on nutrition, so there are certainly

limitations in my review on technical nutrition issues.

## 

## **R**: Thank you for recognising the value and novelty in our manuscript. We have addressed your concerns below - these were all very helpful and we’re grateful for your constructive suggestions.

First, the significance statement and introduction are arguably too modest or vague on

the specific contribution of this paper. Is this the first paper to identify dried fish

contributions to filling nutrient gaps in multiple African countries? If so, say so! And

clarify what other papers have done, and clarify your methodological innovations. This

is important for a contribution worthy of PNAS.

## 

## **R:** Thank you for raising the importance of our study. In our Significance Statement, we now say “*Our results provide the first large-scale analysis of dried fish consumption, underlining their importance for global food security and nutrition.*” We also clarify our methodological innovations in the Introduction: “*These models enabled us to quantify associations between fish consumption and household wealth and physical access to fisheries, and to predict the number of people accessing fresh and dried fish in each country.*” (L106)

Second, while the results section is quite strong and most of the graphs are nicely

constructed, there is still some room for improvement, and also room in the methods

section to clarify some limitations. Some sentences in the methods section give the

impression of representative testing samples, which is clearly not the case, so

limitations around this kind of sampling of fish products need to be discussed. Was the

sampling opportunistic, drawing on various projects over various years, or what is

systematically designed to cover an important array of products? Were some important

fish types or fish-location dyads missing? Full disclosure please.

## 

## **R:** The core sampling was conducted in one trip to markets in Kenya (two locations) and Ghana (two locations), with sampling aimed at collecting key dried fish species in these countries (e.g. omena from Lake Victoria, Kenya; sardinella sp. from Accra, Ghana). During these trips, additional species such as haplochromines were sampled opportunistically, as advised by coauthors working in these regions. While we were unable to sample the full range of dried fish products available to consumers across East and West Africa, studies of dried fish in these countries suggest that our dataset is representative of most dried fish types (see Table S2).

## 

## We also added opportunistic sampling from coauthors on independent field trips (Malawi, Lakshadweep, Seychelles), based on our expert knowledge that these species were frequently consumed in dried forms. We have added these details to the Methods (L421).

Third, and more to my own expertise, the economic components of this paper are

somewhat muddled at times. There isn’t a nice well stated rationale for the models, and

it’s also important to state why you did this kind of Bayesian approach. I would suggest

concisely motivating it as follows. There are several types of literature looking at

determinants of consumption, from small-scale qualitative type research (why do you

consume this and that?), to large-scale econometric demand models focusing primarily

on income and own-price elasticities, as well as some larger scale studies on

determinants of things like child dietary diversity. The qualitative studies are limited by

size and other issues with qualitative research, while the formal economic demand

models usually don’t disaggregate by dried and fresh fish and have other technical

limitations, nor do DHS or MICS surveys. Formal demand models could do so, however,

and that could be an interesting area for future research. Olivier Ecker at IFPRI has done

this for Bangaldesh, distinguishing between (1) farm-raised freshwater fish, (2) wild-

caught marine fish, (3) inland-capture and mixed-source fish and seafood.

https://ebrary.ifpri.org/utils/getfile/collection/p15738coll2/id/134973/filename/135184.

Pdf

## 

## **R:** Thank you for your helpful suggestions to better define our rationale for using a Bayesian approach. We have added context to the main text:

## 

## “*These models allowed us to make statistical inferences about the underlying drivers of fish consumption, drawing on information from a large multinational survey dataset.*” (L235)

## 

## “*This approach allowed us to build on small-scale dietary studies (43,55,56), while refining knowledge from large-scale models of drivers of fish consumption and dietary diversity (31,52,57).*” (L243)

## 

## We have also added a sentence on future research using economic models to investigate price demand / elasticity, citing Ecker & Comstock (ref. 61) (L279). We also note that we don’t distinguish between fish species or sources (wild or farmed), but this is likely to affect prices (L289).

One glaring problem is that while you do have an income/wealth proxy in household

expenditure, you don’t use information on prices. Another issue that some economists

would point out is that your Bayesian model does not factor in economic assumptions

about food demand – it is non-structural. I think that’s okay, but again, it’s about noting

why you do what you do, and what limitations come with it.

## 

## **R:** Thank you for raising the assumptions underlying our statistical approach. We have clarified our model approach (L235), underlying assumptions on price and access proxies (L238, L520-523), and noted a need for further research on economic factors (L279).

On prices, you are implicitly using distance to water bodies as a kind of proxy for both

prices and availability, but you are not very explicit about that. State it as such. But more

ot the point, you don’t tell us why you don’t use prices. Does the LSMS not have either

explicit market prices or unit prices that can be derived from expenditure and quantity

data? (not that price data would require careful and extensive cleaning, especially if unit

prices are used). The price data could be used to look at how fresh and dried fish prices

vary, not only in grams, but in calories, and in various nutrients.

## 

## **R:** While LSMS did collect food price data, this was not standardized between countries. For example, Malawi and Tanzania asked how much was spent on each food product in the 24-hour recall, whereas Cote D’Ivoire and Senegal asked the value of the product in the last 30 days. It was also not clear how prices related to food weights.

## We have now clarified that we are using our distance variables as proxies for both physical access to fish and food prices in main text (L238) and Methods (L520-523).

Moreover, a useful reference here is Headey and Alderman’s (2019) paper on relative caloric prices of healthy and unhealthy foods since they use global data that would include a lot of data

on Africa. Their relative caloric prices are ratios of the price of the cheapest fish calories

(for example) to the price of calories from the cheapest starchy staples in a country. I

looked at their description of relative caloric prices for fish as a whole (RCPs) and see

the following: “*Fish/seafood was moderately expensive in most regions but very expensive in low-income countries, on average. However, there was marked variation in fish/seafood*

*RCPs across developing countries, and sometimes even within regions. For example,*

*fish/seafood calories were 5–6 times more expensive than starchy staple calories in*

*Latin America, the Middle East, and North Africa, but moderately cheap in East and*

*South-East Asia (RCP <5). In Africa, fish/seafood were typically cheaper in coastal*

*countries than in landlocked countries, and were classified in the moderately cheap*

*category in countries such as Tanzania, Senegal, and Cameroon (Figure 4C).* ”

And Figure 4C shows the marked variation in cheapest fish prices in Africa that they are

referring to. There are likely lots of limitations of the data they use, because they

aggregated dried and fresh fish, and probably issues with how representative the

sample is in terms of fish products covered and fish markets covered. But I think the

other critical takeaway from that analysis is that fish are often cheaper (calorically) than

many other animal-sourced foods in sub-Saharan Africa, especially eggs and dairy,

which had extremely high RCPs in most of Africa. So that’s kind of a key point that the

current paper is not really making. Indeed, some studies of child dietary diversity show

that fish is the most commonly consumed animal-sourced foods in Africa, particularly

once a few East African Highland countries are excluded (Kenya, Ethiopia) where dairy

is common. Indeed, dairy production is highly, highly problematic in much of Africa

because of tsetse fly, very high ambient temperatures and other livestock disease

issues. So the fact that dried fish can deliver many of the same nutrients as dairy,

including calcium, is an important point. The Hoddinott-Headey-Hirvonen study on

“animal sourced foods and child stunting” also makes this point, but I am sure there are

other studies out there that could be cited to make this point.

## 

## **R:** Thank you for linking our work to research on food prices and affordability. We absolutely agree that highlighting the affordability of dried fish should be a key point in our paper. We have added several sentences to the main text (L273-282), noting that:

## fish products can be expensive but highly variable in price (Headey & Alderman 2019)

## disaggregated datasets have shown that species that are typically dried (small pelagic fishes) are among the most affordable fish products (Robinson et al. 2022)

## aquatic foods are more affordable than animal-source foods in Africa and SE Asia

## there is a need for further research on fish prices and drivers of demand

Finally, just as the introduction does not explicitly state the novelty of the study’s

contributions, the Conclusions are not very strong on the policy implications. On

demand, you only mention food-based dietary guidelines, but it’s not clear that these

have any impact on consumption. What are some interventions that could improve

consumption of these foods at scale? Here you might talk about interventions specific

to infant and young child feeding practices, but also approaches to reach the

population at large. I would also note that you implicitly find that demand for dried fish

is kind of weak or income inelastic, meaning it does not rise with income. So that’s

potentially a problem if you want dried fish to remain an important part of the diet as

incomes rise, and as a potential complement to fresh fish and other animal sourced

foods. A relevant example here is the relative decline of small fish consumption in

Bangladesh relative to the rapidly growing farm-fish products.

## 

## **R:** Thank you for this comment. While we agree it is not clear if food-based dietary guidelines have a directimpact on individual consumption, food-based dietary guidelines (FBDGs) inform food policies by, for example, providing the scientific and cultural foundation for nutrition standards used in school feeding schemes, public food procurement, and dietary education campaigns. FBDGs thus help ensure that policy-driven food environments like school-feeding programs, institutional meals, or national food subsidies support healthier, more balanced diets that align with national health goals. This is why we chose to mention FBDGs and would like to keep that as a policy point.

We agree that we should mention other interventions, including complementary feeding and large-scale population programmes. We have added these points to our Conclusion (L384-395):

*“Policies and programs to enable and encourage the consumption of dried fish, especially among young children and women, are needed in places where micronutrient deficiencies are prevalent but small dried fish are abundant. Indeed, while cereal fortification programs have been widely implemented to boost intakes of nutrients that are concentrated in dried small fishes (93), dried fish are largely overlooked as a source of micronutrients by food-based dietary guidelines. Practical strategies can involve the inclusion of dried fish products in complementary feeding and malnutrition treatment products (94), school feeding programs (95), and national food aid programs (96). Given the potential small dried fish have on alleviating the burdens of malnutrition, more rigorous studies evaluating their impact on child and nutrition outcomes are needed (20).”*

Second, you mention “Investment in value chains to reduce post-harvest losses,

prevent contamination, and prioritise catches for food instead of animal feeds can

support food security, but should be developed in ways that avoid exacerbating existing

inequalities. ” Okay, but maybe a little more detail here. Are there examples of success

stories? And would “prioritise catches for food” actually entail from a policy point of

View?

## 

## **R:** Thank you for this suggestion. We have developed our conclusion to recommend specific value chain policies that could better support food security, including recognising dried fish at policy level, training and engagement with fishing communities, and removing financial barriers for marginalised groups (L362-373).

## 

Smaller comments

• Line 395: "Samples... are representative of dried fish in island states". I know

what you mean, but I don't think the samples are representative - I think you

mean that these fish species are representative of the type of fish species

consumes in these localities. But as noted above, more discussion is needed on

issues of representativeness and limitations of the food testing sample.

## 

## **R:** This is a good point, thanks. We have changed this sentence to say ‘*species*’ are representative (L424) and, as in our earlier response, added details on the sampling procedure and aim to collect typical and widespread dried fish products (Methods).

• line 495: re-scaling expenditure for each country doesn't make for valid

comparisons across countries because the richest person in one country will not

be as rich as the richest person in another country. In my view it would have been

more appropriate to convert all household expenditure to purchasing power

parity dollars, and then re-scaled, so that the richest people in the whole sample

get a value of 1, irrespective of where they are. This would embed the more

plausible assumption that demand patterns are relatively common across

countries, which is testable, and could be presented in the supplement as

country-specific consumption vs expenditure gradients.

## 

## **R:** Thank you for raising this issue - we agree that our 0-1 scaling simplified purchasing power. We have now estimated the purchasing power of each household, using PPP conversion factors (<https://data.worldbank.org/indicator/PA.NUS.PRVT.PP>), and use this as the wealth covariate in our statistical models. In revising these models, we also realised that combining a 0-1 scaled covariate with mean-centered covariates would lead to different interpretations of effect sizes (i.e. covariates are not on the same scale). Our model covariates are now all mean-centered, revealing stronger effects of household wealth (accounting for PPP) on dried and fresh fish (revised Figs. 2, 3). These results suggest that PPP-standardization is more effective at capturing variability in fish consumption, with wealth associated with (moderately) higher dried fish consumption, and (higher) fresh fish consumption. Household wealth results have been updated in the main text (L270), Figs. 2 and 3, and Methods (L526-530).

• 120-134: I suggest re-writing the sentence below to make it much clearer to the

reader that hereafter you are going to refer to contributions of multiple nutrients

to NRV as “nutrient density”. Something like “multiple nutrients to NRV, which we

hereafter refer to as ‘nutrient density’. This refers to nine nutrients, with a

maximum value of 900%.” I think this is important because there are other

definitions of nutrient density in the literature, such as nutrients per calorie, and

you are using quite a specific definition.

## 

## **R:** Good point, thank you. We have rephrased to say “*We also estimate the nutrient density of dried and fresh fish, defined as the cumulative contribution of nine nutrients to NRV, which has a maximum value of 900%*” (L124).

• what is "study portion relative to our analysis in Table S2"? Not clear what that

means what about salt/sodium consumption of dried fish?

## 

## **R:** We believe this comment refers to our sentence on variation in portion sizes. We have rephrased this sentence to explain that we use a fixed portion size to estimate nutrient intakes, but that empirical studies have shown portion sizes can vary between ⅕ and 3x this value (L134)

• What does "Nested intercept of household cluster (defined by country survey)"

mean? This confused me, because you use GIS variables on the right hand side,

and these would be absorbed by the cluster effects.

## 

## **R:** This varying-intercept effect structure is used to account for non-independence of households, as specified in the survey design (household clusters selected within stratified survey). This estimates a mean and variance for each household cluster, making sure that the model captures any cluster effects (i.e. a fishing community vs. non fishing) that are not captured by the explanatory covariates. These effects are not absorbed by GIS variables (distance to market or water) because households from different clusters (or countries) can have the same distance values (e.g. 1 km from water and market).

• Line 243-2247: these abbreviations for fresh and dried don’t seem necessary.

## 

## **R:** We think these abbreviations help to communicate the results (12 numbers) without having overly duplicated text (Dried, Fresh), and prefer to use this format.

• line 249-250: what is the definition of a market? It can be clarified in the main

text with an appropriate adjective such as open air markets or weekly markets,

etc. PNAS readers will not all be Africa/LMIC specialists, so important to identify

what is meant by a market here. And moreover, are the definitions the same

across countries?

## 

## **R:** We defined ‘distance to markets’ using estimates of travel time to an urban centre (Weiss et al. 2018, *Nature*), and applied it equally to all countries. This dataset identified “*high-density centres*” of “*contiguous cells with a density of at least 1,500 inhabitants per km2 or a density of built-up greater than 50% and a minimum of 50,000 inhabitants*”. We use this metric and assume that urban centres provide greater physical access to cheaper fish than rural areas, following its use for similar purposes in other studies (O’Meara et al 2021, *Global Food Security*). We have clarified in the Methods (L520) and refer to the covariate as ‘proximity to urban centre’ throughout the manuscript.

• 252-256: the higher consumption of dried fish relative to fresh fish in proximity to

water bodies is perhaps surprising, but perhaps obscures the more important

point that dried fish can travel further through remote rural areas, whereas urban

areas have more cold storage and more attractive large markets for fresh fish

supply chains. Moreover, since malnutrition is always higher in rural areas, this

means that dried fish have an added advantage in combating rural malnutrition

than many other foods would not have, included fresh fish. I suggest

commenting on this.

## 

## **R:** Thanks for raising this point. We have added a sentence that local fisheries supply is important for rural communities that can lack access to other animal-source foods (L287).

• A related issue is that wealth and location are correlated (proximity to water

bodies, rural/urban location) and likely interact in determining fish consumption.

For the supplement, at least, it would be interesting to see some aspects of

Figure 3 repeated for sub-samples of poor households and sub-samples of rich.

## 

## **R:** In our models, wealth and location covariates have additive effects on fish consumption. For example, for fresh fish, a wealthy (++) household near to marine water (+) will have higher consumption than is indicated in Fig 3a and d. To demonstrate these contrasts, we have added a supplementary figure showing predicted fish consumption for low and high wealth households (**new Fig. S8**). We note that, in the LSMS dataset, the three proximity variables were weakly correlated (with wealth PPP: r = -0.25 for urban centre, 0.14 for inland, -0.08 for marine).

• Figure 2. panel A could vary between 0 and 100%, but the y and x axis could be

swapped to be consistent with panel B. For Panel B the label "posterior effect"

seems unnecessarily vague: why not just "probability of fish consumption" as in

panel A? And in the notes I think "covariate effect sizes" implies causal effects,

whereas these are just observational results.

## 

## **R:** Thank you for this suggestion. We have revised Figure 2 to show **a**) country predicted fish consumption on the x-axis, and **b**) axis label to indicate ‘*Relative effect size*’. The effect sizes are not probability estimates, but rather the change in consumption per unit of change in the covariate. Our approach (plotted effect sizes) follows recommendations for visualising Bayesian models fit to observational data (e.g. McElreath, *Statistical Rethinking*; Buerkner, *brms: Bayesian regression models using Stan*). However, when interpreting these statistical effects in text, we now refer to covariates having associations with fish consumption (L106).

• Figure 3: maybe drop household size panel e - not particularly interesting results.

## 

## **R:** We prefer to keep this variable in to retain consistency with Figure 2, and to ensure that all predictors with strong effects are shown in the main text.

• 103 and abstract: why not just write "by 60 percent" instead of 1.6 to 1.

## 

## **R:** We now express this result as a percentage.

• line 322: “although fishery-independent surveys suggest population biomass in

Lake Victoria has remained 321 steady as fishing effort has increased (63),

landings and nutrient supply available to consumers have 322 declined (64). ”

what does "landings" mean in this context?

## 

## **R:** Landings refers to the total catch from a fishery. We have clarified.

• Line 346: You write “benefits. Furthermore, dried fish value chains face growing

pressure from 346 increasingly competitive markets (79)….”. To an economist,

this sentence sounds a bit strange. Competitive markets are a good thing

because they produce the lowest prices for consumers! But I think what you

mean here is not really competitive markets, but just foreign fleets competing for

a finite natural resource. Moreover, it’s questionable as to whether this is really a

market as opposed to just plundering a poorly regulated natural resource. The

Coase theorem states that someone has to have property rights over a resource

for competitive markets to work, though there are also issues of corruption in

management of these resources, I suspect.

## 

## **R:** Thanks for raising this distinction. We have clarified this issue relates to increasingly competitive international markets, and link overfishing with foreign fleets practicing illegal fishing (L350-354).

• line 349: increases in fish prices, not fish price.

## **R:** Changed to ‘prices’.

• line 365: "every week" is not appropriate as it's just referring to a 1-week recall.

## **R:** We have removed ‘every week’ as the survey format is not needed to understand this result.

• You might also use some of these surveys, such as Malawi LSMS, to explore

whether there's any seasonality in fresh and dried fish consumption, since the

Malawi lsms was staggerd across a 12 month period.

## 

## **R:** We agree that it would be useful to examine seasonality in consumption. However, most of the surveys are conducted in ‘waves’ throughout a year, and as a result there may be a geographic pattern when regions and household clusters are sampled. For example, in Côte D’Ivoire and Senegal, half of households were surveyed in Sept-Dec, and half in April-July. In our models, this might risk confounding ‘month of survey’ with other measured (rural/urban) and unmeasured (religion, ethnicity, language) variables. We now suggest that seasonality could be important in wild fisheries, as a future research direction: “*Fish consumption may therefore correlate with fisheries production levels, suggesting that LSMS data could be used to explore the influence of seasonality, fishery status, and fishing effort on diets*” (L292)

**Reviewer 2**

This is an extremely clearly written detailed and robust empirical study on an important but under-researched subject - the importance of dried fish in diets in Africa - that convincingly triangulates multiple data sources. Happy to recommend for publication with only a few very minor adjustments

## **R:** Thank you for your positive assessment and recommendation.

1) Abstract and P9: Dried fish consumption exceeded fresh by a ratio of 1.6:1 - is this ratio calculated taking into account the wet weight of dried fish (i.e. accounting for weight loss during processing) or is the a ratio of dry weight to wet weight? Please make this explicit

## 

## **R:** We used LSMS data on fish consumption (yes/no) that did not include portion sizes. We have clarified that this result refers to consumption rates.

2) P7 - dried fish was more prevalent in Uganda (F = 14%, D = 11%) - it seems fresh was more prevalent, or the prevalence was similar, not that dried was more

## 

## **R**: Thank you for noticing this detail. The text result was incorrect and did not line up with Figure 2. We have amended the text: “*dried fish was more prevalent…in Uganda (F = 3%, D = 27%)”* (L249).

3) P7: "Fresh fish consumption declined with increasing distance from inland water, which could be due to fresh fish being prioritised for international export markets e.g., (Nile perch, Lates niloticus)" - This explanation seems spurious. very little fresh water fish exported (to outside Africa) as a share of total catch, and from few fisheries (only lake Victoria, mostly Kenya). Please drop

## **R:** We agree this discussion point was more focused on Lake Victoria fisheries and may not hold in other locations. We have removed this sentence.

4) P7: "Fresh fish thus persisted relatively further from markets (but at lower consumption than dried fish), possibly due to cold-store networks": This explanation also seems spurious. More likely explanation is scattered water bodies holding fresh fish found in many places far from markets

## 

## **R:** We agree we do not have data to test this explanation. Our analysis also quantified household distance to large water bodies but did not include rivers or smaller lakes. We have added this (potential) explanation for the fresh fish ~ urban market effect (L285).