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Economic impacts and nutritional outcomes of the 2017 floods in Bangladeshi Shodagor fishing families

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Abstract

Objectives: As climate change continues to increase the frequency and severity of flooding in Bangladesh and globally, it becomes increasingly critical to understand the pathways through which flooding influences health outcomes, particularly in lower-income and subsistence-based communities. We aim to assess economic pathways that link flooding to nutritional outcomes among Shodagor fishing families in Bangladesh.

Methods: We examine longitudinal economic data on kilograms of fish caught, the income earned from those fish, and household food expenditures (as a proxy for dietary intake) from before, during, and after severe flooding in August–September of 2017 to enumerate the impacts of flooding on Shodagor economics and nutrition. We also analyze seasonally collected anthropometric data to model the effects of flooding and household food expenditures on child growth rates and changes to adult body size.

Results: While Shodagor fishing income declined during the 2017 flooding, food expenditures simultaneously spiked with market inflation, and rice became the predominant expenditure only during and immediately following the flood. Our nutritional models show that children and adults lost more body mass in households that spent more money on rice during the flood. Shodagor children lost an average of 0.36 BMI-for-age z-scores and adults lost an average of 0.32 BMI units during the flooded 2017 rainy season, and these metrics continued to decline across subsequent seasons and did not recover by the end of the study period in 2019.

Conclusions: These results show major flood-induced economic impacts that contributed to loss of child and adult body mass among Shodagor fishing families in Bangladesh. More frequent and severe flooding will exacerbate these nutritional insults, and more work is needed to effectively stabilize household nutrition throughout natural disasters and economic hardship.

1 | INTRODUCTION

Flooding is one of the most commonly reported types of natural disasters worldwide (EM-DAT, 2022). It is associated with negative impacts on human biology and health outcomes and disproportionately impacts people living in low-income settings around the world (Alderman et al., 2012). As anthropogenic climate change continues to exacerbate global warming trends, floods are becoming more frequent and more severe, causing death, illness, injuries, and damage to homes, infrastructure, and resources (Brunner et al., 2021; Uhe et al., 2019). Low-income populations inhabit many of the areas most vulnerable to extreme climatic events, including flooding, and are poised to suffer unprecedented consequences (Kulp & Strauss, 2019). Therefore, it is critical to understand the pathways through which flooding influences biological outcomes for humans in these socioecologies so that interventions may be targeted in ways that are most effective.

In Bangladesh, which was classified by the World Bank, 2020 as a "lower-middle income" country, people have been experiencing worsening effects of climate change for more than two decades (Hasan & Macdonald, 2021). Here, fishers comprise a major sector of the country's economy, with around 11 million people working as fishers throughout the year (Azim et al., 2002), but are among the poorest households (Nurul et al., 2011). Bangladeshis identifying with the Shodagor ethnicity, who are traditionally boat-dwelling and semi-nomadic subsistence fishers, represent an even poorer community, typically holding much less wealth and lower status than other fishers throughout the country. Additionally, their lifestyle and livelihoods are closely tied to local ecological conditions (Starkweather, 2017). For these reasons, we expect that they may experience the effects of flooding even more acutely than other communities in the country, but also that they may serve as a model for understanding the mechanisms that link flooding to biological outcomes related to health and nutrition.

Worldwide, flooding events have an important impact on the health of human populations in a number of ways (Ahern et al., 2005; Alderman et al., 2012; Lieber et al., 2022; Noji, 1997; Rosinger et al., this issue). Flooding in low-income areas has been linked with an increased risk of disease, such as diarrhea (Biswas et al., 1999; Mondal et al., 2001), cholera (Sur et al., 2000), and respiratory infection (Biswas et al., 1999). It is also associated with greater food insecurity (Morshed et al., 2022; Parvez et al., 2022) and poor growth and nutritional outcomes (Choudhury & Bhuiya, 1993; del Ninno & Lundberg, 2005; Rodriguez-Llanes et al., 2011; Stewart et al., 1990). Growth and nutritional outcomes are useful to examine because they are important indicators of diet as well as overall health. For instance, poor growth could indicate major or minor immune insults from disease and/or infection (Garcia et al., 2020; Urlacher et al., 2018), or could be due to consuming fewer calories—as a result of either resource shortages or the inability of some people to access resources (Banerjee, 2007; del Ninno et al., 2003; Paul & Rasid, 1993). While there are various pathways through which flooding can affect growth and biological outcomes, we will focus here on potential economic and nutritional pathways (Figure 1) and examine the impact of flooding on child growth and adult body size in a Shodagor fishing community in Matlab, Bangladesh.

1.1 | Bangladesh 2017 flood

In late August through September, 2017, Bangladesh experienced severe flooding throughout the country. This

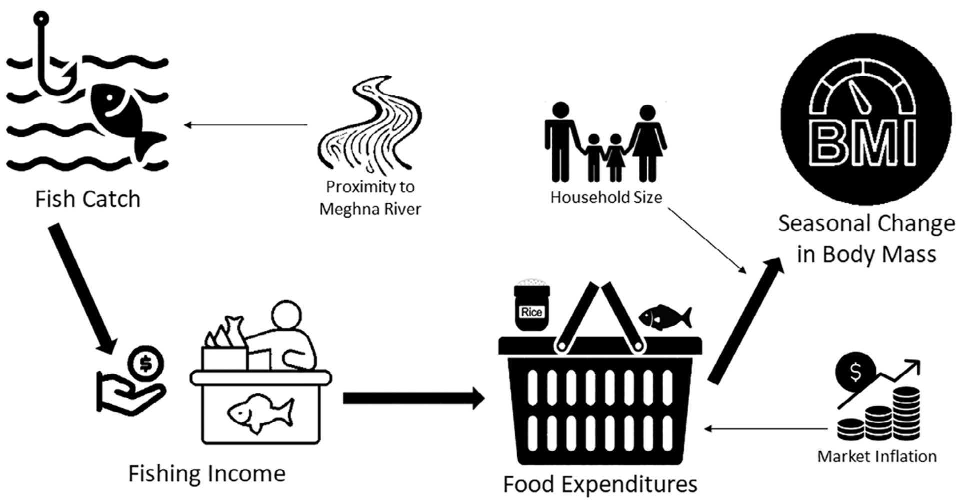

FIGURE 1 Predicted socioeconomic pathways of flooding impacts on Shodagor child growth and adult body mass

was one of its worst flooding events in recent history, which scientists have attributed to anthropogenic climate change (Philip et al., 2019). This kind of extreme flooding is distinct from the regular, annual landscape flooding that parts of the country experience between May and October every year and, consequently, often has devastating effects. The severe flooding in 2017 caused death and injuries, loss of livestock and food supplies, and damage to housing and infrastructure. Flood-induced loss of rice crop, the country's main staple food, contributed to rice prices reaching record levels in September 2017, increasing by 30% over the previous year's prices (Food and Agriculture Organization of the United Nations, 2017).

During this time, Shodagor communities living on the land were also experiencing severe flooding: Some homes were partially underwater and families reported damage to their properties, including erosion of land under and around their homes. Many Shodagor families (those living on land and in boats) reported a decrease in fishing yield and income, as well as general economic hardship in late-August and early- and mid-September. Given the known links between flooding and nutritional outcomes (del Ninno & Lundberg, 2005), we expect the poorer fishing outcomes and economic hardship reported by Shodagor families to have negatively impacted child growth and adult nutritional status during and following the 2017 flooding.

Here, we examine economic data, in the form of kilograms of fish caught and income from selling those fish in local markets, and data on household food expenditures (as a proxy for dietary intake) from before, during, and after the flooding in 2017 to enumerate any direct changes to household economics and diet during that time period. We also compare data from the same time periods in 2018 to determine whether or not fishing success or income were different in 2017 than in the subsequent year. Finally, we examine seasonally collected anthropometric data. We use these data to determine the effects of flooding and household food expenditures on child growth rates and changes to adult body size.

2 | MATERIALS AND METHODS

2.1 | Study population

Shodagor communities in Matlab, Bangladesh are traditionally semi-nomadic, boat-dwelling fishers and traders who are culturally distinct from the majority ethnicity in the country. Matlab, the mostly rural subdistrict where this research was conducted, is home to approximately 500 Shodagor families as well as 230 000 Bangladeshis who are majority Muslim, minority Hindu, and primarily work as agriculturalists, wage laborers, and housewives and do not identify with the Shodagor ethnicity (ICDDR,B, 2018). Branches of the Meghna River make up the northern and southern borders of the region, which is also bisected by a second large river, the Dhonagoda River, its streams and canals. At the time of data collection (2017–2019), the Dhonagoda was home to around 150 Shodagor families who are the primary focus of this study. These families reside on small, wooden houseboats, clustered within five distinct groups along the rivers and canals, or have moved onto the land within the previous 10 years and live in make-shift houses on the riverbanks. Nearly all families live in nuclear family households, but in groups with extended family members.

Fishing and trading are the two primary occupations of adults in the Matlab Shodagor communities, leading to a mixed subsistence and cash economy. During the rainy season every year, almost all adult men and about half of adult women fish intensively. All fishing is riverine, typically using a form of hook-and-line method that targets small- and medium-sized catfish. At the end of each day, fish may be consumed by the household, but are usually sold in local markets in exchange for cash, which is then used to buy other foods and goods. In 2014, 89% of households reported eating some of their own catch, and the Shodagor diet is heavily reliant on fish- both from a family's own catch and from the market- as well as rice, lentils (daal), and occasionally vegetables, chicken, beef, and processed market foods. Fishing is a reliable economic endeavor (Starkweather et al., 2020), which is also most profitable throughout Matlab during the rainy season. During this time, households report saving all of their excess income to use during times of economic difficulty over the coming year. Therefore, any economic insults suffered during the rainy season (smaller catches or lower income) are seen as cause for great concern.

2.2 | Shodagor anthropometrics

While malnutrition and malnutrition-related mortality in Bangladesh have fallen dramatically over the past 20 years, as of 2017, approximately 31% of children under 5 years of age were considered stunted, falling more than two standard deviations below the WHO standards for height-for-age, and 22% were wasted, falling more than two standard deviations below the weight-for-age standards (National Institute of Population Research and Training, 2019). In Matlab, children from the non-Shodagor, majority groups show similar trends (Das et al., 2015). Among Shodagor children, data from 2014 show that 43% fell more than two standard deviations below the WHO standards in height-for-age, 23% in weight-for-age, and 21% in BMI-for-age (Starkweather & Keith, 2018). This could indicate that Shodagor children are particularly vulnerable to malnutrition, however, international growth standards are largely derived from urban populations and designed to reflect the growth of children under nonlimiting conditions, which may not be appropriate for assessing growth in non-Western or subsistence-based societies (Blackwell et al., 2017; Guedes et al., 2010; Hakeem et al., 2004; Hasan et al., 2001; Martin et al., 2019; Urlacher et al., 2016). Using growth standards specific to the Shodagor, only 4% of Shodagor children fell more than two standard deviations below the mean in height-for-age, 2% in weight-for-age, and 2% in BMI-for-age (Starkweather & Keith, 2018). While these population-specific measures indicate that Shodagor children may not be at high risk of serious malnutrition generally, we expect that major nutritional insults or significant loss of body mass in children and adults would be problematic and indicate decline in population health and well-being.

The primary anthropometric outcome variable of interest for this study is body mass index (BMI). While this measure can be problematic in a number of ways, including that it is not a direct or reliable measure of adiposity, it is a useful measure of population-level health (Green, 2016). It is also a highly plastic measure that captures short-term changes in nutritional status and is known to respond seasonally to nutritional stressors among adults and children (Sellen, 2000). Furthermore, in several subsistence-based populations that vary substantially from WHO child growth standards in height-for-age and weight-for-age, BMI-for-age shows much closer congruence (Blackwell et al., 2017; Urlacher et al., 2016).

2.3 | Data collection

Data for this study come from interviews and anthropometric measurements that were collected between 2014 and 2019 with all available members of Shodagor families in Matlab who either lived on boats at the time of data collection or had recently moved onto the land. Demographic data (age, gender, household size) were collected and updated between 2014 and 2019. Longitudinal data on fish catch, fish income, household expenditures, and anthropometrics used in this study were collected over 27 months between May 2017 and July 2019. Anthropometrics were collected seasonally in March/April at the end of each dry season and again in September/October at the end of each rainy season. Interview data were collected as repeat measures before, during, and after the flooding in 2017, and during the same time periods in 2017, 2018, and 2019. As some Shodagor households are seminomadic, the location of the family's residence was also recorded each time an interview was conducted. For the purposes of this study, locations were grouped together based on their distance to the Meghna River. Fishing is generally most profitable and reliable year-round for families who live closer (within 5 km) to the Meghna, while fishing is more reliable during the rainy season for those living more than 5 km away. Thus, families living within 5 km from the Meghna were coded as "close" and those living more than 5 km away were coded as "not close."

Missing data are due to individuals being absent during a particular season, children being born after data collection began in 2017, an individual's death, or declining to participate. This study includes descriptive data from 52 children between the ages of 0–18 and 50 adults from 31 households for whom complete nutritional and demographic data were available in the flooded 2017 rainy season (Table 1). All data were collected in accordance with procedures approved by the University of Missouri's Institutional Review Board, the International Center for Diarrhoeal Disease Research, Bangladesh's (ICDDR, B) Research and Ethical Review Committees, and the Max Planck Institute for Evolutionary Anthropology's Department of Human Behavior, Ecology, and Culture.

2.4 | Data analysis

We first compared fish catch and income from the 2017 flood year between July and October to the same months in 2018. These data were collected via interview up to four times per month from all available adults in every household. Husbands and wives were interviewed together, if possible, about their catch size and the income earned from it. If not possible, the person who sold the fish in the market (usually the husband) was interviewed. Respondents were asked to provide these data for the previous 3 days on which they worked. Household levels of daily reported fish catch and income were plotted with median trends for a sample of 155 households with 1935 daily measures between July and October 2017 and for 141 households with 2407 daily measures between July and October 2018 (Figure S1). Population-level aggregates of fish catch and income were also plotted at monthly intervals for a subset of 20 households who each had one set of three-day measures across all months from July–October in both 2017 and 2018 (Figure 2).

TABLE 1 Descriptive statistics for 50 adults and 52 children from 31 Shodagor households with fish catch, income, food expenditure, and anthropometric data during the 2017 flooding

	n	Mean	Median	Standard deviation	Min	Max
Number living in household	31	4.13	4.00	1.45	2.00	8.00
Living ≤ 5 km to the Meghna river (1 = yes, 0 = no)	31	0.35	0.00	0.59	0.00	1.00
September 2017 daily fish catch (kg)	217	1.80	2.00	1.04	0.00	7.00
September 2017 daily fish income (taka)	217	596.30	540.00	394.97	0.00	1810.00
September 2017 daily rice expenditure (taka)	230	84.70	90.00	69.66	0.00	395.00
September 2017 daily fish expenditure (taka)	230	40.28	0.00	73.21	0.00	300.00
September 2017 daily meat expenditure (taka)	230	15.74	0.00	69.90	0.00	600.00
September 2017 daily vegetable expenditure (taka)	230	28.86	30.00	23.76	0.00	100.00
September 2017 daily other food expenditure (taka)	230	54.50	50.00	49.10	0.00	550.00
September 2017 daily total food expenditure (taka)	230	224.10	194.50	149.37	0.00	1025.00
Child age (years)	52	9.08	9.25	4.01	0.50	17.50
Adult age (years)	50	39.88	38.50	12.20	20.50	73.50
Sex (1 = female, 0 = male)	102	0.49	0.00	0.50	0.00	1.00
Child height-for-age (z-score)	52	−1.63	−1.75	1.31	−4.49	2.20
Child weight-for-age (z-score)	24	−1.05	−1.14	1.16	−2.95	2.97
Child BMI-for-age (z-score)	52	−0.30	−0.31	1.27	−4.83	2.54
Change in child BMI-for-age (z-score)	52	−0.33	−0.42	1.53	−5.31	6.10
Adult BMI (kg/m^2)	50	22.20	20.85	4.15	15.48	32.46
Change in adult BMI (kg/m^2)	50	−0.37	−0.43	1.93	−4.84	4.33

Note: Fish catch, income, expenditure, and location data at the household level; demographic and anthropometric data at the individual level. Child anthropometric *z*-scores calculated from WHO standards (ages 0–18 height-for-age and BMI-for-age, ages 0–10 weight-for-age). Height-for-age, weight-for-age, BMI-for-age, and BMI reported from the end of the 2017 rainy season; change in BMI-for-age and BMI measure individual change from the beginning to end of the 2017 rainy season (April–October).

Husbands and wives were also interviewed about household food expenditures and asked to list all of the items on which they spent money during the previous 3 days. For this study, food expenditures were categorized into the following groups: Rice, fish, meat, vegetables, and other. Rice, fish, meat (which includes chicken, beef, and mutton), and vegetables were the four items that people most commonly reported spending money on, while the "other" category includes all other types of foods and condiments, such as oil, lentils, salt, fruits, and more processed market foods and snacks. Using continuous data from May 2017 through July 2019 at monthly intervals, we examined population-level aggregate food expenditure trends for 27 households who each had one set of 3-day measures across all 27 months (Figure 3).

In order to examine how the 2017 flooding impacted Shodagor nutritional status, we assessed variation in seasonal growth and body mass fluctuations. Anthropometric data were collected from all available children and adults in the population at the end of each rainy season (September/October) and at the end of each dry season (March/April) from the dry 2017-dry 2019 season, resulting in a possible maximum of five measurements per person. Weights to the nearest 0.1 kg were collected using an electronic scale in a firm, flat surface. Heights to the nearest 0.1 cm were measured using a Seca stadiometer. From these measurements, BMI was calculated for all children and adults using the standard formula (weight [kg]/height [m^2]). All measurement procedures followed standard techniques (Lohman et al., 1988). Child height-for-age, weight-for-age, and BMI-for-age *z*-scores were calculated according to WHO growth standards using the "zscorer" package in R v. 4.1.1 (Myatt & Guevarra, 2019; R Core Team, 2021). Seasonal changes in these measures were calculated by subtracting age- and sex-specific *z*-scores at the end of the current season from that of the previous season, and 149 children (75 female) between ages 0 and 18 included in this sample had an average of 2.9 seasonal deltas each between the dry 2017 and dry 2019 seasons (Figure S2). Seasonal changes in adult BMI were calculated by subtracting BMI at the end of the current season from that of the previous season, and 134 adults (70 female) included in this sample had an average of 3.1 seasonal deltas each (Figure S3).

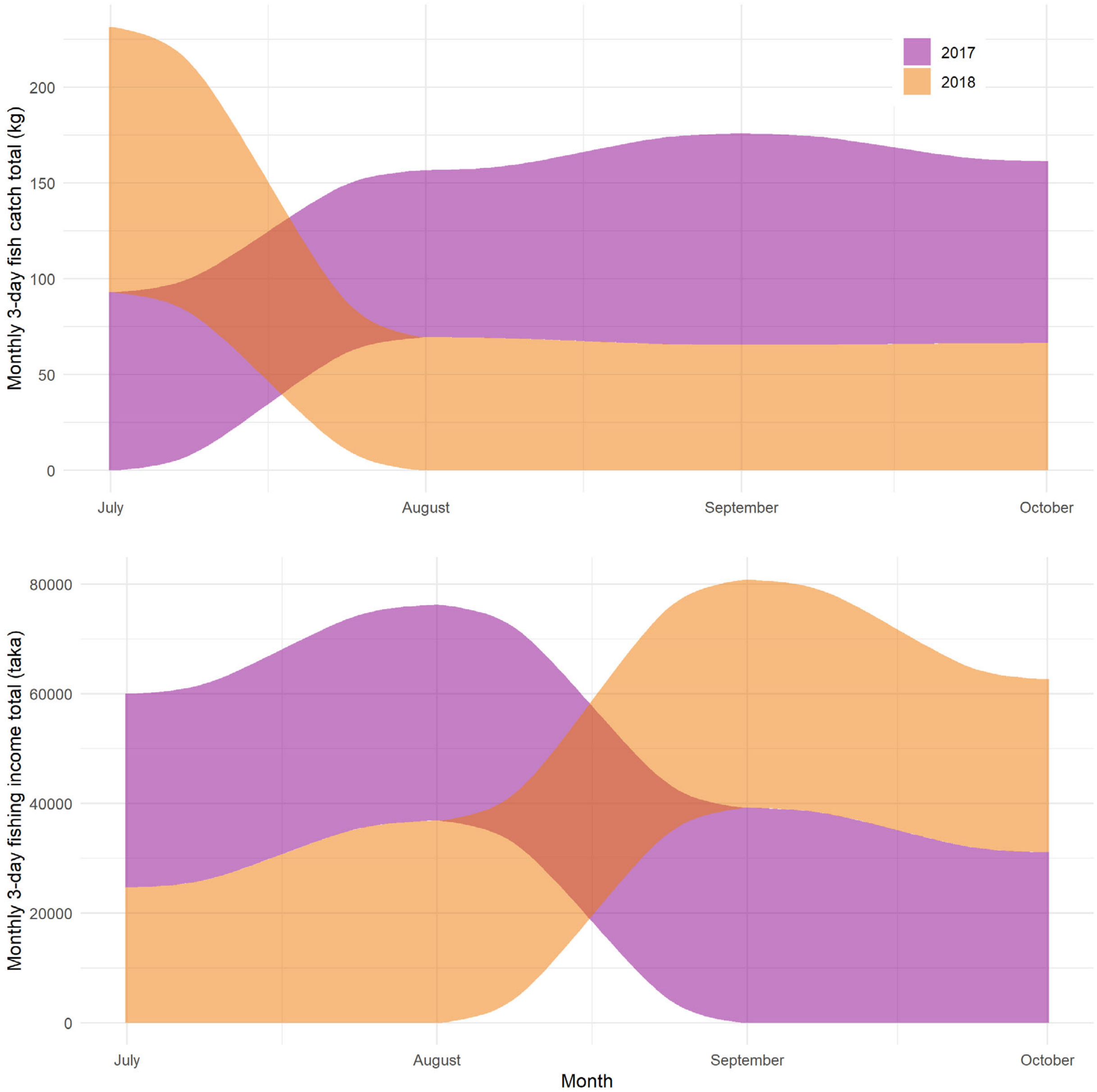

FIGURE 2 Monthly population aggregates ($n = 20$ households with complete data) compare three-day fish catch (top) and income (bottom) totals from July to October 2017 versus 2018

We compared seasonal changes in child BMI-for-age *z*-scores and changes in adult BMI during the flooded 2017 rainy season to body mass changes during the subsequent three seasons using Bayesian linear mixed models with the "brms" package in R v. 4.1.1 (Bürkner, 2017). Specific seasons were modeled as a fixed effect with the rainy 2017 season set as the reference, individual ID was included as a random effect in order to account for repeated measures across seasons, and we retained the package default weakly-informative priors.

To assess proximate dietary impacts on body mass during the flooded 2017 rainy season, we modeled the effects of categorical food expenditures (as proxies for household nutritional intake) on the seasonal changes in child BMI-for-age *z*-scores and adult BMI (Figure 1). Upon examining the temporal trends during the 2017 rainy season (Figure 3), we focused on household expenditures during the month of September and calculated the median expenditure amount for each household on rice, fish, vegetables, and meat. We excluded the 'other' expenditure category given its broad and variable dietary contributions, and no households had median meat expenditures greater than zero in September 2017, therefore, these models included September 2017 median household expenditures for rice, fish, and vegetables as predictors of the rainy 2017 seasonal changes in child

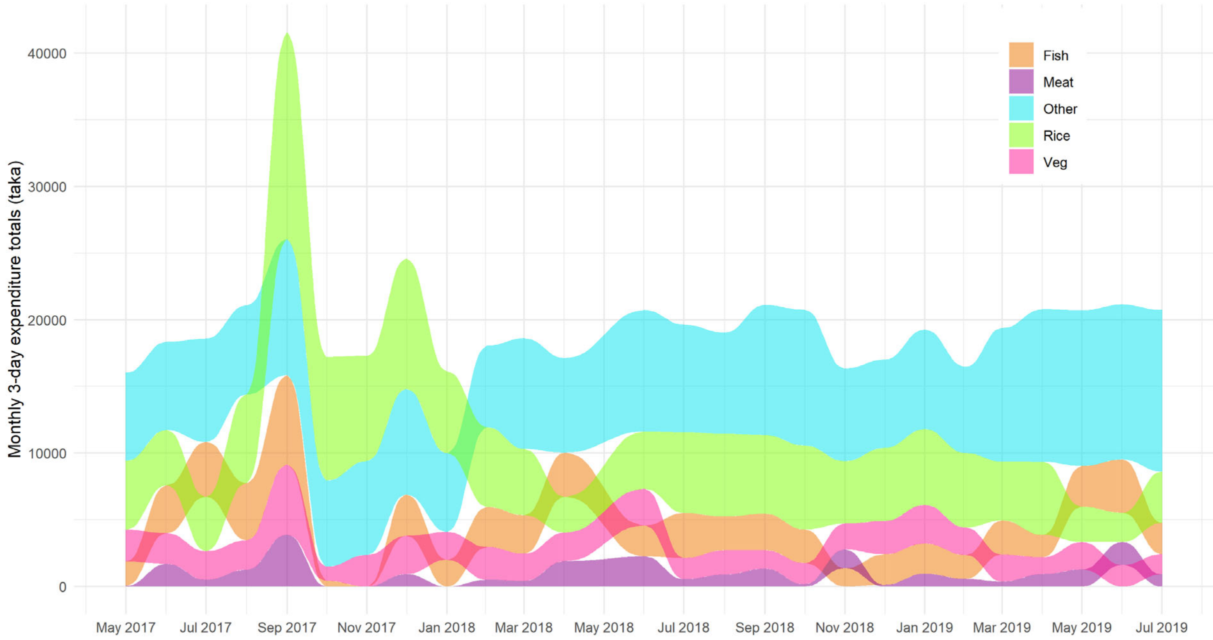

FIGURE 3 Monthly population aggregates ($n = 27$ households with complete data) of three-day rice, fish, meat, vegetable, and other food expenditure totals from May 2017 to July 2019

and adult body mass. These Bayesian linear mixed models also included the number of individuals living in each household and the family's proximity to the Meghna River (≤ or >5 km away) during the rainy 2017 season as fixed effects, as well as a random effect for each household ID to account for structured variance among common household environments from unspecified sources. Samples for these models included 52 children (25 females) between the ages of 0–18 and 50 adults (25 females) from 31 different households for whom complete expenditure, demographic, and anthropometric data were available during the 2017 rainy season (Table 1). Models of seasonal change in child BMI-for-age z-scores and seasonal change in adult BMI used a half-Cauchy prior for random effects with a scale parameter of one, a normal intercept prior with a mean of zero and standard deviation of 0.5, and a normal prior for fixed effects with a mean of zero and standard deviation of one. We ran four chains for each model for 2000 iterations with a warmup of 1000 in "brms" (Bürkner, 2017; R Core Team, 2021), all effective sample sizes exceeded 1000 parameter estimates from the posteriors, and all Gelman-Rubin convergence statistics were approximately 1.00. Altogether, the analyzes above assessed the impacts of 2017 flooding on household fish catch, income, food expenditures, and individual nutritional status among this Shodagor community in Matlab, Bangladesh. The data and code for these analyzes are publicly available on GitHub at: https://github.com/mhkeith/Shodagor_FloodImpacts_AJHB.

3 | RESULTS

3.1 | Flooding impacts household economics and nutrition

Longitudinal economic data show that Shodagor fishing income was negatively affected by the severe flooding in September 2017 (Figures 2 and S1) while household food expenditures simultaneously spiked (Figure 3). Comparing fishing yields before, during, and after the 2017 flooding to the same time period in 2018 shows that while household median catch and income were comparable in early August of both years, fish catch weights were slightly higher in late August and September during the 2017 flooding, yet the income earned off of these catches was lower compared with 2018 (Figure S1). These daily fishing data also show that a few households were catching very large quantities of fish in early August 2017, but these high yields then dipped during the flooding and rose again in October 2017, and yet the incomes from these catches in 2017 show a relatively dampened response (Figure S1). Monthly population-level aggregates mirror these daily household-level trends, showing higher total fish yield in August–October 2017 than 2018 but lower income earned off of those catches in September and October 2017 (Figure 2).

Trends in continuous monthly food expenditures from May 2017 to July 2019 show a large spike in total population-level expenditures during the September 2017 flooding and higher categorical expenditures on rice, fish, vegetables, and meat during this month than any other

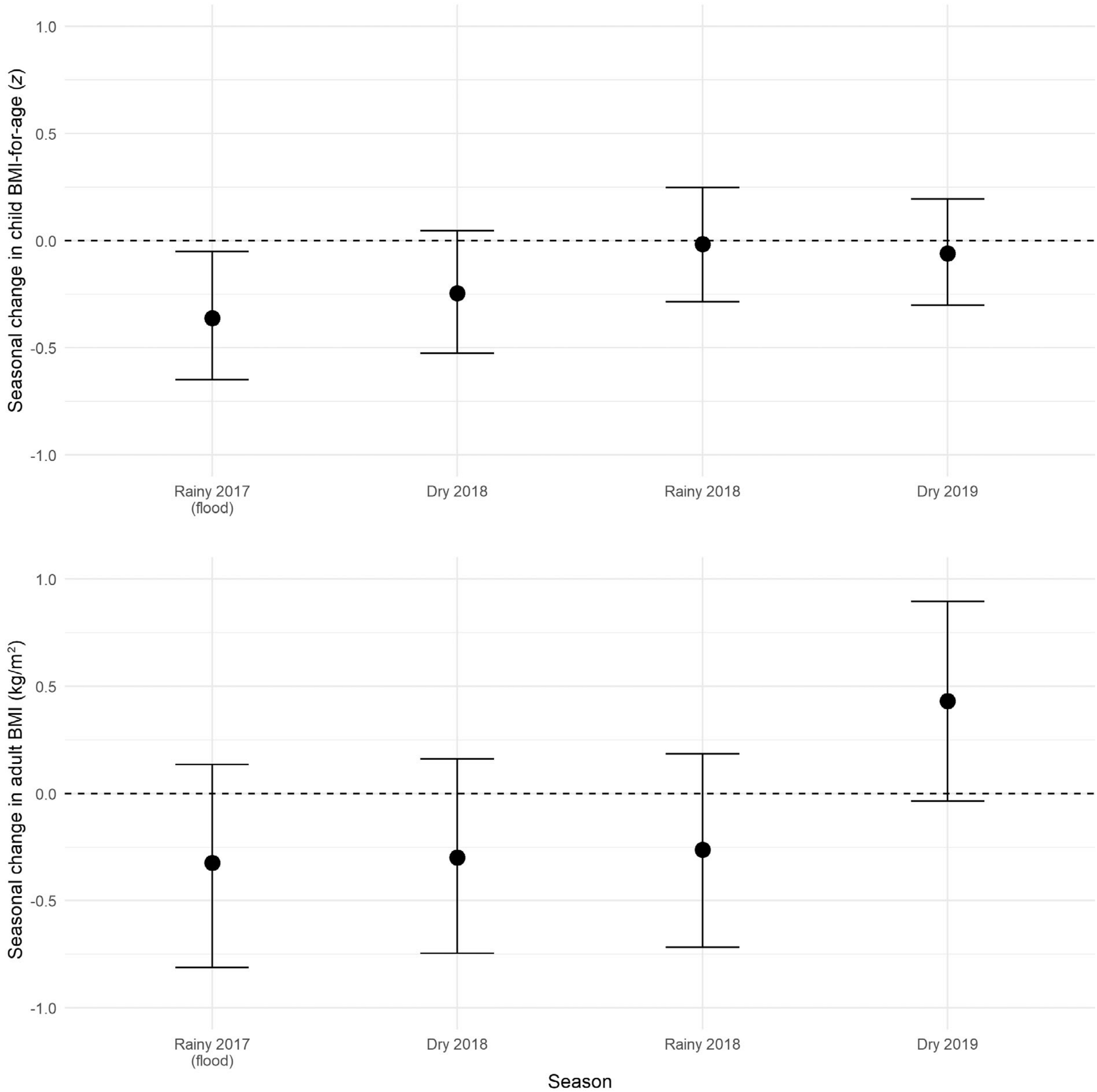

FIGURE 4 Conditional effects of seasonal ecology on change in child BMI-for-age z-scores ($n = 149$, 432 observations) (top) and change in adult BMI ($n = 134$, 416 observations) (bottom) since the previous season. Mean posterior estimates and 95% credible intervals account for repeated measures with individual random effects

(Figure 3). Total food expenditures were nearly double in price during September 2017 than any other month. The time period during and immediately following the flooding (September 2017–January 2018) was also the only period during which rice was the highest expenditure among Shodagor families. Meat was consistently the lowest Shodagor food expenditure (Figure 3), and no families had median daily meat expenditures above zero during the 2017 flooding (Table 1). Daily household-level data indicate that fish was the most variable expenditure between families during the 2017 flooding and vegetables the least variable (Table 1).

3.2 | Flooding impacts child growth and adult body mass

Seasonal changes in child BMI-for-age and adult BMI show that the 2017 flooding had negative and sustained impacts on nutritional status among children and adults (Figure 4). Models that account for individual variance in seasonally repeated measures show that body mass decreased an average of 0.36 z-scores among Shodagor children and an average of 0.32 BMI units among adults during the 2017 flooding (Table S1). Given that the outcomes in these models measure the change in body mass from the beginning to end of each season (April–October rainy, October–April dry), estimates of zero indicate that child BMI-for-age or adult BMI has remained stable since the previous season, whereas estimates below zero indicate decreasing body mass since the previous season and estimates above zero indicate a relative gain in body mass since the previous season. Visualizations of seasonal anthropometric changes do not show marked differences across sex or age (Figures S2–S4).

Child BMI-for-age *z*-scores decreased the most during the flooded 2017 rainy season (with the entire 95% credible interval falling below zero) and continued to decline during the subsequent dry 2018 season (Figure 4). While BMI-for-age then appeared more stable for children during the rainy 2018 and dry 2019 seasons, average seasonal changes did not rise above zero, indicating that the earlier lost body mass was not effectively recovered by the end of the dry 2019 season (Figure 4, Table S1). Marginal and conditional R^2 estimates from this model indicate that approximately 14% of the variation among seasonal changes in child BMI-for-age is captured by effects of season-specific ecologies, and this increases to 18% by also accounting for individual random-level effects in these repeated data (Lüdecke et al., 2021). 11.5% of the children in this Shodagor sample were underweight (falling more than two SD below the WHO mean BMI-for-age) at the end of the 2017 rainy season (Table 1).

Adult BMI also decreased the most during the flooded 2017 rainy season and then continued to decline during the subsequent two seasons (Figure 4). Unlike child BMI-for-age, adult BMI appears to have recovered some during the dry 2019 season with adults gaining an average of 0.43 BMI units (the equivalent of 2–3 pounds for women and men of average height). However, cumulatively across the rainy 2017 through dry 2019 seasons, the average Shodagor adult experienced a net loss of approximately 0.44 BMI units while the average Shodagor child lost 0.67 BMI-for-age *z*-score units. Marginal and conditional R^2 estimates from the seasonal adult BMI model indicate that approximately 22% of the variation among seasonal BMI changes is explained by specific seasonal ecologies, increasing to 24% by also accounting for individual random-level effects in this seasonally repeated measure (Table S1). Fourteen percentage of Shodagor adults in this sample were underweight (BMI < 18.5) at the end of the 2017 rainy season (Table 1).

Modeling the effects of food expenditures (as proxies for nutritional intake) during the 2017 flooding shows that both children and adults lost more body mass in households that purchased more rice (Figure 5, Table S2). Children were able to retain or gain more body mass in households that purchased more fish, whereas higher fish expenditures in

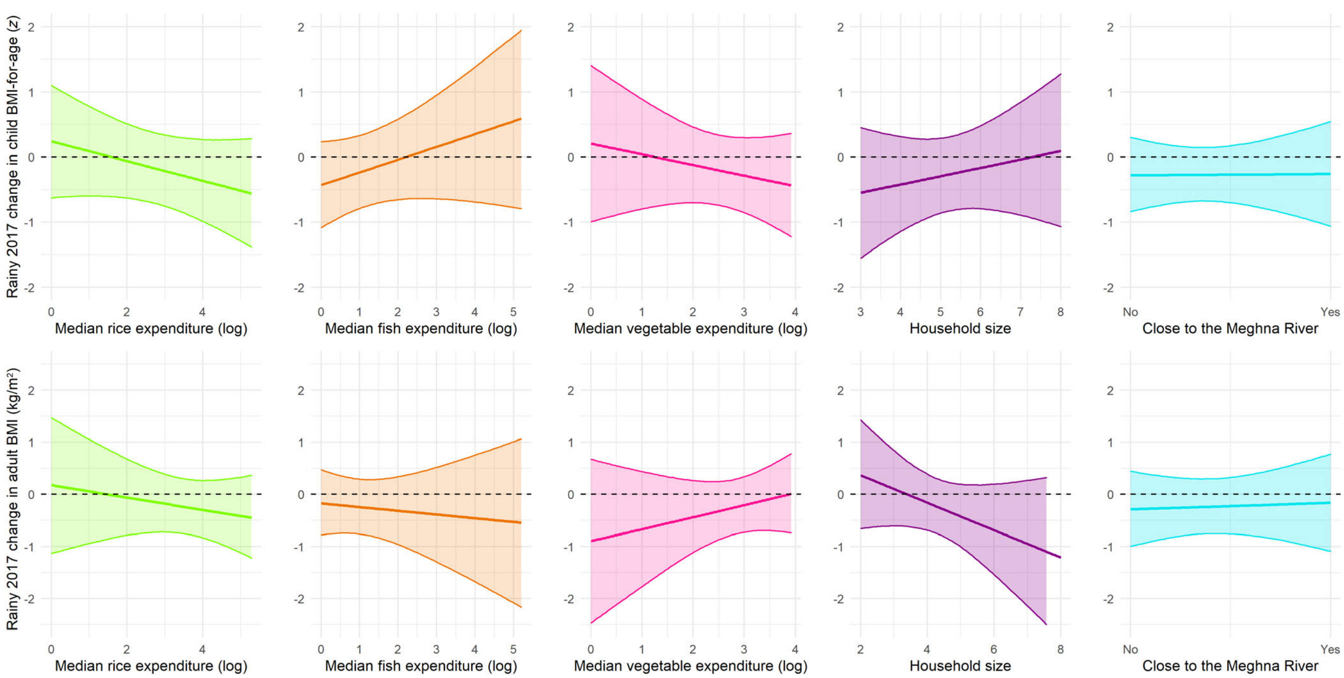

FIGURE 5 Conditional effects of food expenditures (household medians in September 2017), household size, and proximity to the Meghna river on change in child BMI-for-age z-scores (n = 52, 28 households) (top) and change in adult BMI (n = 50, 31 households) (bottom) during the flooded 2017 season. Mean posterior estimates and 95% credible intervals are also conditional on random household effects

September 2017 had a slightly negative association with change in adult BMI. Adults in households who purchased the most vegetables were better able to maintain their BMI, whereas vegetable expenditures had little effect on child BMI-for-age but trended in a negative direction. Modeling total household food expenditures rather than specific rice, fish, and vegetable categories showed no discernible impacts on child nor adult body mass (results not shown). Household size had the largest effect of any modeled predictor on change in adult BMI. Adults in larger families lost more BMI during the flooded 2017 season whereas household size had a weaker but positively trending effect on the seasonal change in child BMI-for-age (Figure 5, Table S2). Proximity to the Meghna River (which proxies household access to higher fishing yields versus market centers) shows no impact on child nor adult body mass. R^2 estimates indicate that categorical food expenditures, family size, and household location explain 15% of the variation in seasonal body mass changes among children and 14% of the variation among adults during the 2017 rainy season, and the amount of variation explained in these outcomes increases to 17% for children and 28% for adults by also accounting for common household environments with a random-level effect (Table S2).

4 | DISCUSSION

Our results in a Bangladeshi Shodagor fishing community elucidate economic and nutritional pathways through which flooding events can affect health and biological outcomes in a low-income community. These economic data and nutritional models suggest that the severe flooding in 2017 negatively impacted health among Bangladeshi Shodagor families by temporarily increasing dietary reliance on rice which contributed to loss of body mass among both children and adults (Figures 3 and 5). Across five seasons of food expenditure data, rice was the largest expenditure only during the flooded rainy 2017 season and subsequent dry 2018 season (Figure 3), coinciding with sustained losses in child and adult body mass that were not recovered by the end of the study period in 2019 (Figure 4). Furthermore, our flood nutrition model results show that both children and adults lost more body mass during the 2017 rainy season in households that spent more on rice during the worst market inflation (Figure 5). Positive effects of fish and vegetable expenditures on child and adult nutrition, respectively, show that more diverse and higher-quality dietary components are needed to sustain growth and stabilize nutritional status.

4.1 | Flooding led to high food expenditures and low fishing income among Shodagor families

In August and September of 2017, when flood waters peaked in Matlab, we (Starkweather and Zohora) were visiting Shodagor households daily to conduct interviews. Some of the effects of flooding were evident in Shodagor communities: homes on the land (i.e., those that were not boats) were flooded, with several inches of standing water covering their floors, and flood waters covered communal cooking areas and wells. Many Shodagor adults living both on land and in boats reported that fishing was "bad," incomes were lower, and they were experiencing general economic difficulties.

Income earned from fishing dropped in September and October of 2017, during and following the weeks when flooding was highest in Matlab (Figure 2). This was both relative to income earned in the months prior to the flooding and relative to the same time period in 2018, which was a year without severe flooding. Unexpectedly, fish catch showed the opposite patterns whereby kilograms of fish caught were higher in August, September, and October of 2017 than they were during the same months in 2018 (Figures 2 and S1). This indicates that during the 2017 flood, fishers were catching more fish but earning less money for their catches than in the following year. While the income pattern is consistent with fishers' anecdotal reports, the pattern of kilograms of fish caught is not. When asked in 2022, Shodagor fishers suggested that a likely reason for this was that, although the volume of fish they were catching remained high during the flooding, the types of fish they were able to catch were lower-value. They agreed that the higher water levels made it more difficult to catch fish that are more desirable by consumers and for which they can make more money when selling at the markets.

Household food expenditures during the flooding clearly support Shodagor reports of economic hardship during this time (Figure 3). In September of 2017, expenditures on rice, fish, vegetables, and meat were higher than at any other point between May 2017 and July 2019. Rather than indicating that families were buying (and, therefore, consuming) more food, these data appear to reflect the nation-wide, flood-related inflation that Bangladesh was experiencing at the time, which was primarily fueled by rising food prices (Reuters, 2017). This echoes a similar pattern among lower-income Bangladeshi households following the 1998 floods in which household expenditures spiked due to rising food costs and loss of rice crop (del Ninno et al., 2003).

While inflated prices of fish, meat, and vegetables that were reported throughout Bangladesh in 2017

(Reuters, 2017) are evident in Shodagor families' expenditures, rice expenditures show the most striking pattern in these data (Figure 3). Rice is the staple of the Shodagor diet, as is the case for households throughout Bangladesh. In 2017, three different flooding incidents (in March/April, July, and August/September) led to the damage or destruction of hundreds of thousands of hectares of rice crop in Bangladesh (FAO, 2017). Mostly as a result of these losses, rice prices reached record levels in September 2017, climbing 30% higher than the same period in the previous year, which led to food insecurity among households throughout the country (FAO, 2017). While our economic data show that rice was the largest Shodagor expenditure only during and immediately after the 2017 flooding (Figure 3), these data do not directly show whether the increase in Shodagor rice expenditures reflects only an increase in rice prices (i.e., households were buying the same amount of rice but paying much more) or whether they also reflect a change in food expenditure priorities such that households were both paying more for rice, but also buying and consuming more rice than at other times relative to other foods. While some studies show decreasing rice consumption as prices increase (e.g., Schmidt et al., 2021), previous findings in Bangladesh indicate that surging rice prices lead to reduced nonrice food consumption among households who purchase rather than produce rice (Hasan, 2016). In these Shodagor data, we assessed the relationships between specific food expenditures and seasonal changes in body mass during the 2017 flooding to inform whether the observed changes in food expenditures also reflected changes in food consumption.

4.2 | Flooding and food inflation led to loss of body mass among Shodagor fishing families

Rice expenditures in September 2017 showed a negative relationship with change in child BMI-for-age and adult BMI, indicating that Shodagor children and adults lost more body mass in households that spent more money on rice during the 2017 flooding (Figure 5, Table S2). This is fully consistent with other studies that show relationships between increased expenditures on rice and other grains and negative outcomes for growth and body size (Campbell et al., 2010; Sari et al., 2010; Torlesse et al., 2003). In rural Bangladesh between 1992 and 2000, the percentage of underweight preschool children increased when rice prices were high, due to rice making up a higher proportion of the diet and more nutrient-dense foods making up a lower proportion (Torlesse et al., 2003). Following the 1998 flooding in Bangladesh, poorer households that were exposed to flooding increased the per capita daily quantities of rice consumed, despite inflated rice prices during that time (del Ninno et al., 2003). Decreased consumption of other types of food led to lower caloric intake for people in flooded households, which contributed to increases in wasting and stunting for young children (del Ninno et al., 2003). While we do not have direct dietary data for Shodagor households at the time of the flood, we expect our results to be due to similar reasons. That is, families are consuming fewer nonrice foods, like fish, meats, or vegetables, and increasing their dietary reliance on rice, causing nutritional status of adults and children to suffer. While much progress in food security has been made across Asia in recent decades, large spikes and volatility in rice prices continue to threaten food security with detrimental impacts in low-income communities throughout South Asia (Timmer, 2014). Our results indicate that the flooding-induced rice inflation in 2017 negatively impacted health and nutrition among Shodagor fishing families in Matlab.

Prices also spiked on fish and vegetables during this time, however, fish expenditures associated positively with child BMI-for-age, and adults were able to retain more body mass in households that spent the most on vegetables (Figure 5, Table S2). Although fish expenditures had a weaker effect on adult BMI than on child BMI-for-age, the association trends negatively for adults. Across cultures, there is a broad range of variation in how food is allocated among family members. In some cases, adults are given priority over children (e.g., Dettwyler, 2013) or males are prioritized over females (Chen et al., 1981; Kong & Osberg, 2018). Others report no obvious differences in food allocation based on age or gender (Graham, 1997), and still others have reported preferential allocation to children over adults (Kaiser & Dewey, 1991; Leonard, 1991). Informal interviews with Shodagor parents indicate that in times of economic shock or hardship, they preferentially allocate higher-quality foods, including fish, to children instead of themselves, which is consistent with these fish expenditure results. This is consistent with a study among Bangladeshi women living in the Dhaka slums, who reported decreasing their own food intake during times of flooding and extreme economic hardship, in order to allocate more food to their children (Goudet et al., 2011). Our model results also showed varying effects of vegetable expenditures on child and adult body mass, trending in a positive direction among adults and a negative direction among children (Figure 5, Table S2). In general, vegetables are routinely one of the lowest Shodagor food expenditures (Figure 3) and it is not clear what this pattern might suggest, however, it is possible that when households spend more on vegetables, they may spend less on other foods, like fish, that children are more likely or willing to eat. These results may also indicate overall positive effects for household members of greater dietary diversity, as has been shown elsewhere (Campbell et al., 2010; Sari et al., 2010).

Like fish and vegetable expenditures, household size showed varying effects on child and adult body mass with children in larger households showing slightly higher BMI-for-age and adults in larger households showing lower BMI (Figure 5, Table S2). This is largely consistent with results from 2014 data in this population where we found that fathers had lower weight and BMI in households with more children, but household size had no impact on child BMI and a slightly positive association with child weight (Starkweather & Keith, 2018). This pattern coupled with the differential impact of fish expenditures on children and adults supports the anecdotal reporting and observations that Shodagor parents prioritize their children's nutrition at mealtimes, sometimes to their own nutritional detriment. Despite this, Shodagor children still experienced decreasing body mass during and after the 2017 flooding.

Across four seasons of anthropometric data (rainy 2017–dry 2019), Shodagor children and adults showed the largest losses in body mass during the flooded 2017 rainy season (Figure 4). Child BMI-for-age and adult BMI continued to decline in the subsequent dry 2018 season during which rice prices remained high and rice remained the largest household expenditure (Figure 3). With estimated seasonal averages remaining below zero across the study period, Shodagor children did not appear to regain their lost body mass by the end of the 2019 dry season, whereas adults appear to have recovered a portion of lost body mass during the dry 2019 season but still averaged a net loss across seasons (Figure 4, Table S1). Growth stunting also followed the 1998 floods among non-Shodagor Bangladeshi children under age five (del Ninno & Lundberg, 2005), and in India, exposure to flooding has been associated with long-term malnutrition among children under five (Rodriguez-Llanes et al., 2011). These Shodagor data indicate that child and adult nutrition was impacted for several seasons due to severe flooding in 2017, which may reflect sustained economic hardship following losses due to lower income and inflation during the flood.

5 | CONCLUSIONS

As climate change continues to cause more frequent and severe flooding in Bangladesh and elsewhere, it becomes increasingly important to mitigate its harmful health effects (Alderman et al., 2012; Kulp & Strauss, 2019). Low-income and subsistence-based populations, such as the Shodagor fishing communities in Matlab, are directly tied to local ecological conditions financially and nutritionally and are thus poised to face worsening food insecurity (Mirza, 2011). The longitudinal fishing, income, nutritional, and biological data in these analyzes span the severe 2017 flooding in Bangladesh and show major flood-induced economic impacts that contributed to loss of child and adult body mass among Shodagor fishing families. While Shodagor income earned from fish catches declined during the 2017 flooding, food expenditures simultaneously spiked with market inflation and rice became the predominant expenditure only during and immediately following the flood. Children and adults in households that spent more money on rice showed greater losses in body mass. Body mass continued to decline among Shodagor children in the dry season following the flooding and among adults across two subsequent seasons after the flooding, with net losses sustained for children and adults across the four-season period of this study. More frequent flooding will exacerbate these nutritional insults, and the flood-induced economic consequences of poorer fishing income and spikes in food inflation will further stress household finances and families' ability to meet basic caloric and nutritional requirements. Although policy interventions in Bangladesh that subsidize food production and imported food relief have helped to suppress inflation to an extent and stave off severe famine following major crop losses (del Ninno et al., 2003; Dorosh & Shahabuddin, 2002; Reuters, 2021), more work is needed, especially among lower-income rice-consumers, to stabilize household nutrition throughout worsening natural disasters and economic hardship (Parvez et al., 2022; Timmer, 2014).

AUTHOR CONTRIBUTIONS

Kathrine Starkweather: Conceptualization, funding acquisition, investigation, methodology, project administration, writing; **Monica Keith:** Conceptualization, formal analysis, methodology, writing; **Fatema tuz Zohora**: Investigation, project administration; **Nurul Alam:** Project administration, supervision, writing.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in GitHub at https://github.com/mhkeith/Shodagor_FloodImpacts_AJHB.

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SUPPORTING INFORMATION

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