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Rice-aquaculture systems and dietary quality in Bangladesh

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Abstract

Rice-aquaculture is promoted in many countries as a system that could simultaneously improve land and water productivity and household diets and nutrition. However, studies evaluating the effects of rice-aquaculture adoption on household diets do not yet exist. Here, we address this research gap, using data from a survey of 720 households in rural Bangladesh and different statistical techniques to control for possible selection bias. Contrary to expectations, our data suggest that adopting rice-aquaculture is associated with a decrease in household dietary quality, especially during the agricultural lean season. Households with young household heads, low education levels, and small landholdings are over-proportionally affected. We also analyze possible mechanisms of these unexpected negative diet effects. Households adopting rice-aquaculture spend much more time on farming, leaving less time for cooking, other domestic tasks, and certain off-farm activities. Adopters have lower crop and livestock production diversity, lower income from forest extraction activities, and higher debts than non-adopters. Our findings suggest that policies to promote the adoption of rice-aquaculture should consider the broader effects on household livelihoods and provide sufficient support in order to avoid undesirable social outcomes.

Keywords**:** rice-aquaculture, dietary diversity, household time allocation, farm production diversity

JEL Codes: Q10, R29, Q18, E23

1. Introduction

Malnutrition is a major global threat, affecting nearly one-third of the world's population (FAO, 2023). Smallholder farmers in low- and middle-income countries are particularly vulnerable to malnutrition due to their limited access to healthy and diverse diets (Sibhatu et al., 2015). Since smallholder farmers tend to consume a large proportion of the food they produce, higher levels of farm production diversity are often promoted to improve household dietary quality and nutrition (Ruel et al., 2018; Sibhatu et al., 2015). Rice-aquaculture systems, where rice and aquatic species are grown in the same plots, stand out as a potential farm diversification strategy (CGIAR, 2023; FAO, 2024). Rice-aquaculture can help improve land and water productivity, contribute to high-value protein and micronutrient supply, and provide stable income and employment opportunities across seasons. Therefore, it is hypothesized that adopting rice-aquaculture could positively affect household diets and nutrition. However, this hypothesis has not yet been tested empirically. Previous studies on rice-aquaculture have mainly focused on economic and environmental effects, not on diet or nutrition outcomes. It is well known from other contexts that positive productivity and income effects do not always lead to improved diets and nutrition (Knößlsdorfer et al., 2021). Furthermore, harvested aquatic species might possibly be sold to markets in wealthier areas rather than being used for own consumption and local markets (CGIAR, 2023). In this study, we analyze whether the adoption of rice-aquaculture actually improves farm household diets, as hypothesized.

Several studies examine the economic effects of adopting rice-aquaculture with ambiguous results. A few studies show that rice-aquaculture positively affects farm productivity and income (Dubois et al., 2019; Onoh et al., 2020; Saiful et al., 2015; Yu et al., 2023). Farming rice and aquatic species together in the same plot can benefit both species. Aquatic species (e.g., fish) can benefit rice by improving soil fertility and controlling pests, diseases, and weeds. Rice, in turn, may regulate the water environment for the aquatic species by reducing ammonia, providing shade, maintaining a suitable temperature, and offering supplemental feed sources such as planthoppers (Xie et al., 2011). However, the assumption of mutually beneficial relationships may not always hold in reality. Studies suggest that in some situations rice-aquaculture does not increase farm productivity and may even reduce rice yields, depending on stocking density and other management factors (Hu et al., 2016; Sun et al., 2019; Vromant et al., 2002; Wang et al., 2024). Furthermore, rice-aquaculture systems are labor-intensive and require high initial capital investments (Dey et al., 2013). This means that adoption may have broader effects on household livelihood strategies and change the resource allocation to various farm and off-farm activities.

The main research objectives pursued in this study are (i) to examine mean effects of adopting rice-aquaculture on household dietary quality (measured in terms of household-level and individual-level dietary diversity), (ii) to investigate heterogeneous effects of adoption on diets by differentiating between agricultural seasons and various farm and household characteristics, and (iii) to examine possible channels through which adoption affects diets, particularly focusing on time allocation, income, and farm production diversity. To our knowledge, all three objectives have not been analyzed before.

For the analysis, we use primary survey data from Bangladesh, where nutritional deficiencies are widespread. Recent data suggest that around one-third of the population in Bangladesh suffers from severe food insecurity during the lean season (GRFC, 2024). In Bangladesh, 80% of the total crop area is used for rice production. Rice-aquaculture systems have been promoted in the country since the 1990s by WorldFish, other international agricultural research centers, and national institutions (Freed et al., 2021; Ignowski et al., 2023).

The subsequent sections are structured as follows: Section 2 presents a conceptual framework explaining the potential interrelationship between rice-aquaculture adoption and household dietary quality, as well as the possible impact mechanisms. Section 3 provides information on the study area, data collection, and the methods of data analysis. The empirical results are presented and discussed in section 4. Finally, section 5 summarizes the main findings and discusses policy implications.

2. Conceptual framework

Figure 1 presents the conceptual framework, illustrating the different mechanisms through which rice-aquaculture adoption could affect household dietary diversity. In particular, we assume that adopting rice-aquaculture could affect household dietary diversity through household time allocation, income, and farm production diversity.

In terms of time allocation, as mentioned above, rice-aquaculture is a labor-intensive system. If much of the household time is allocated to rice-aquaculture, less time may be available for other income-earning and household activities. For example, due to increased involvement in farming, household members may have less time for non-farm wage employment or seasonal migration. There may also be less time for food preparation and other domestic tasks, which are often managed by women. Studies show that less time for domestic activities may possibly be associated with negative diet and nutrition outcomes (Debela et al., 2021). Foods prepared in the household may be less diverse. Also, the increased time spent on farming might decrease the time spent on collecting wild foods, which are an important source of household dietary diversity in many rural contexts (Iannotti et al., 2024; Cheek et al., 2023; Sunderland, 2023).

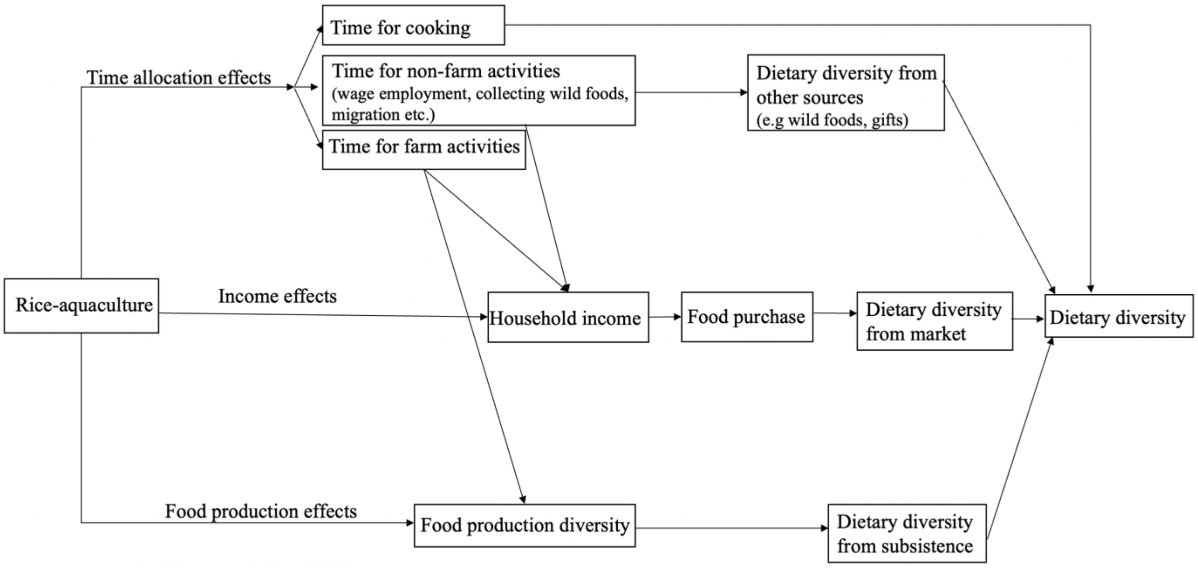

Figure 1. Conceptual framework

In terms of income effects, it is possible that adopting rice-aquaculture positively impacts farm income by enhancing rice yield and generating an additional income source. However, due to the time-allocation effects, other income sources may also be affected. Assuming that the total income effects are positive, a higher income may increase food purchases and make diverse and healthy diets more affordable, even though the concrete outcomes also depend on how the additional income is spent.

In terms of farm production diversity, rice-aquaculture systems are typically adopted by rice farmers, so adding aquatic species may increase the diversity of what is produced on the farm. Previous studies have shown that farm production diversity is positively correlated with household dietary diversity in many situations, as smallholders often consume a certain portion of what they produce at home (Headey et al., 2018, Sibhatu et al., 2015; Pandey et al., 2016; Powell et al., 2015; Yan et al., 2024). However, smallholder rice farmers rarely grow rice as the only crop, and some may also keep livestock such as cattle or chicken. Adopting rice-aquaculture may possibly influence these other farming activities through competition for labor and capital, meaning that the net effects on farm production diversity are uncertain. We will analyze these mechanisms empirically, using our data from farm households in Bangladesh.

3. Materials and methods

3.1 Study area and data collection

Data for this study were collected in three districts, namely, Khulna, Satkhira, and Bagerhat, located in the south-west region of Bangladesh. This region is densely populated, heavily dependent on agriculture, and has high levels of poverty and food insecurity. Around 40% of the local population in the study districts are engaged in the agricultural sector (Alam, 2017). Rice cultivation is the most common livelihood observed. Both men and women are involved in the agricultural labor force, with average daily working hours of 7.6 and 7.0, respectively (BBS, 2022). Around 30% of the local population suffer from severe food insecurity (Shuvo et al., 2024). The study area is adjacent to the Sundarbans, the world’s largest mangrove forest. Apart from rice farming, forest extraction and aquaculture are also common local livelihood strategies.

Rice-aquaculture systems have been extensively researched in Bangladesh since the mid-1980s by various government and non-governmental organizations, including the Bangladesh Fisheries Research Institute (BFRI), the Bangladesh Rice Research Institute (BRRI), the Bangladesh Agricultural University (BAU), the Department of Fisheries (DOF), and the WorldFish Center (Dey et al., 2013). WorldFish, the International Rice Research Institute (IRRI), and the CGIAR more broadly promote rice-aquaculture for additional income generation and to make local smallholder farming more nutrition-sensitive (CGIAR, 2023; IRRI, 2019; WorldFish, 2018). We collected data from both rice-aquaculture adopting and non-adopting households.

Our sample of farm households in the three districts of south-west Bangladesh was selected using a three-stage random sampling procedure. First, eight Upazilas (communities) were randomly selected, whereby the number Upazilas chosen in each district was proportional to the district population size. Next, we randomly selected 36 villages from the eight Upazilas (Figure 2). Finally, we randomly selected 20 farm households from each village, resulting in a total sample of 720 households. All sample households grow rice. Out of the 720 households, 157 (22%) have adopted rice-aquaculture while 653 have not. As we use a random sample, this adoption rate can be considered representative for the study area.

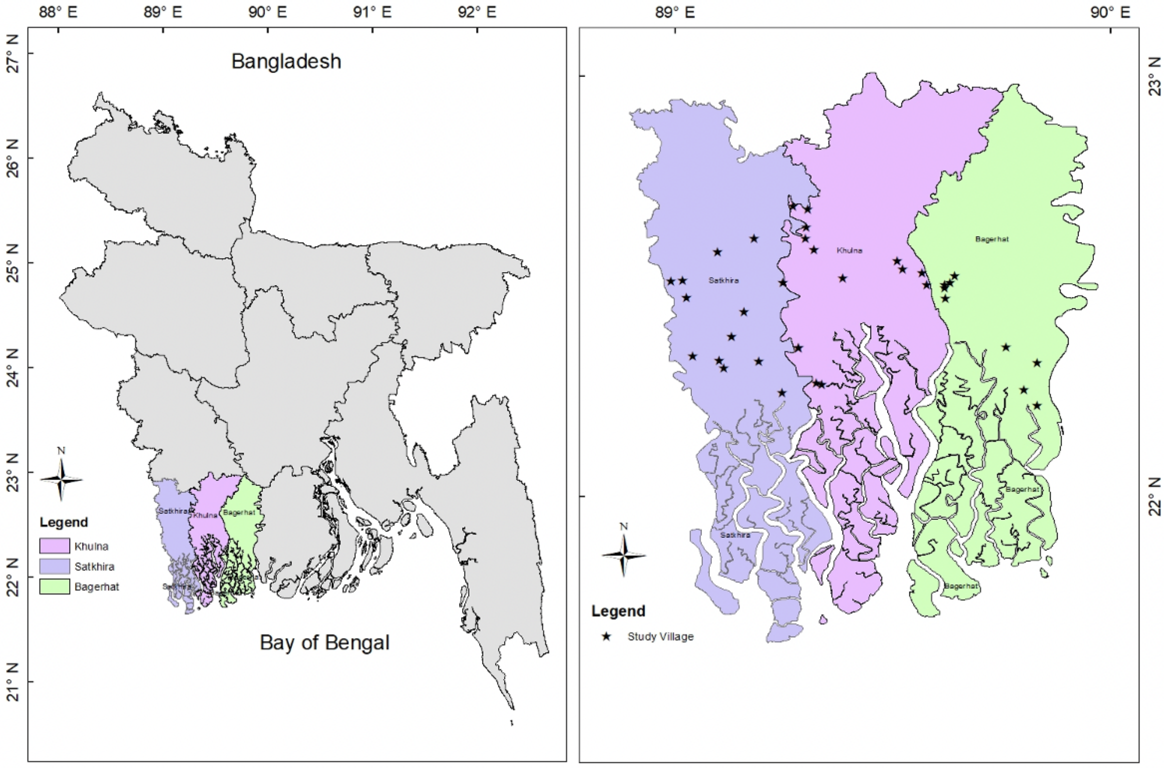

Figure 2. Map of the study area

The survey was implemented in October and November 2023, using a structured questionnaire for personal interviews with household heads and other household members. The questionnaire included sections on general household demographics, education levels, agriculture and aquaculture production, forest extraction activities, non-farm wage employment, vulnerability and resilience, household assets, savings, and credit access. Details on food consumption and diets were collected through food frequency questions. At the household level, the household head or the person responsible for cooking was asked about the number of times the household had consumed specific food items during the last seven days. The survey took place during the “normal season”, where local food availability is better than during the lean season. However, since aquaculture is less affected by seasonality than rice and other crops, we separately also asked for the household consumption of food items during an “average week” in the lean season.

In addition to the household-level food consumption, we collected data on individual-level diets by asking household members whether they had eaten various food groups during the last 24 hours. This individual dietary information was collected only for the “normal season” from one male adult, one female adult, and one child in each household, whenever available. For children under the age of 10, the dietary questions were answered by the primary caregiver.

From male and female adults, we also collected details on individual time use per day, employing a list of 16 common work- and non-work-related activities in the study area during different seasons of the year (Lader et al., 2006; Stinson, 1999). For the “normal season”, we asked individuals for their time use during the last 24 hours prior to the survey. For the “lean season”, we asked for their time use during an average lean season day. Following Mehraban et al. (2022), we asked respondents about which concrete activity they performed during 30-minute intervals between 5:00 am and midnight (assuming that the remaining time would be occupied with sleeping and/or resting).

The agricultural section of the questionnaire covered information on planted areas, crop species grown, production costs, output quantities, and sales. The livestock and aquaculture sections included details on species kept, production costs, main products and by-products, revenues, and potential losses. For non-farm income sources, including wage employment, self-employment, and remittances and transfers, we recorded information for all household members on a monthly basis. We explicitly tried to capture individual income for an average month during the last one year, considering that economic activities may vary seasonally. In addition, we collected data on household consumption over the last one month, including food and non-food goods and services (e.g., transportation, communication, health care, education, personal care and clothing, etc.).

3.2. Outcome variables

Indicators of dietary quality

We measure dietary quality in terms of dietary diversity at household and individual levels, which is a common approach in the literature (Muthini et al., 2020; Ruel et al., 2018). Household dietary diversity is assessed using the household dietary diversity score (HDDS), counting the number of different food groups the household consumed over a 7-day period. We consider the following 12 groups, as recommended by FAO (2011): (1) cereals, (2) white roots and tubers, (3) vegetables, (4) fruits, (5) meat, (6) eggs, (7) fish, (8) legumes, nuts, and seeds, (9) milk and dairy products, (10) oils and fats, (11) sugar and sweets, and (12) spices, condiments, and beverages. We refer to this indicator as HDDS12. However, the last three of the 12 food groups are generally considered less healthy (low in micronutrients), which is why HDDS with the first nine food groups is sometimes calculated as an alternative proxy of household dietary quality (Parlasca et al., 2020; Sibhatu et al., 2015). We do so as well and refer to this alternative indicator as HDDS9. Both, HDDS12 and HDDS9 are calculated separately for the “normal season” and the “lean season” because we collected household-level food consumption data for both seasons, as explained above.

For the normal season, we also have individual-level 24h dietary data from several household members, which we use to calculate women’s dietary diversity score (WDDS), men’s dietary diversity score (MDDS), and children’s dietary diversity score (CDDS). Each of these individual-level scores has its own food group classification to account for different nutritional needs (FAO, 2011). In particular, for MDDS and WDDS we use the following nine food groups: (1) starchy staples, (2) dark green leafy vegetables, (3) other vitamin A-rich fruits and vegetables, (4) other fruits and vegetables, (5) organ meat, (6) meat and fish, (7) eggs, (8) legumes, nuts, and seeds, and (9) milk and dairy products (Muthini et al., 2020). For CDDS, we use the following seven food groups: (1) grains and tubers, (2) legumes and nuts, (3) milk and dairy products, (4) flesh foods (meat, organ meat, and fish), (5) eggs, (6) vitamin A-rich fruits and vegetables, and (7) other fruits and vegetables (Agbadi et al., 2017; Muthini et al., 2020).

Other outcomes for analysis of mechanisms

As explained in the conceptual framework, rice-aquaculture adoption may influence dietary diversity through various mechanisms, including time allocation, income, and farm production diversity. To construct useful indicators of time use, we aggregated the various activities of male and female adults into six categories, namely (1) farm activities, (2) non-farm activities, including wage employment and self-employment, (3) commuting, also including the travel time between the homestead and the farm’s fields, (4) cooking and other domestic activities, (5) forest extraction such as wild food collection, logging, and hunting, and (6) other activities (e.g., sleeping, eating, personal care, taking care of children and older members). Forest extraction is separately included because this is an important source of food and income for many households, especially during the lean season. We calculate the average daily number of minutes spent on each activity for the normal season and the lean season.

We calculate monthly income in per capita terms from various sources, namely farm income, off-farm income, forest extraction income, remittances and transfers, and total income. In addition, we are interested in how the income is spent and calculate monthly per capita consumption expenditures for total consumption and various expenditure categories of interest, namely food, transportation and communication, electricity and water, health care, education, and other non-food items (e.g., personal care and clothing, social gatherings, fees, fines, etc.). Income and expenditures are measured in Bangladeshi taka (BDT).

Farm production diversity is measured by counting the number of food groups a household produces. We use the same food group classification as for HDDS12 and HDDS9 and separately calculate farm production diversity scores with twelve food groups (PDS12) and nine food groups (PDS9). In addition, we create a production diversity indicator by simply counting the number of crop, livestock, and aquaculture species produced by each household.

3.3. Regression models

To examine the effects of adopting rice-aquaculture on dietary diversity we estimate regression models of the following type:

$$DDS_i = \theta + \beta A_i + \gamma X_i + \alpha D_i + \varepsilon_i \tag{1}$$

where DDS_i is the dietary diversity score of household *i* or an individual belonging to household *i*. We estimate separate models for HDDS12 and HDDS9 during the normal and lean seasons. In addition, we estimate individual-level dietary diversity for adults and children

(MDDS, WDDS, CDDS). A_i is a binary variable indicating whether or not the household has adopted rice-aquaculture. X_i is a vector of household and contextual control variables, and D_i is a vector of district fixed effects. Control variables include age and education of the household head, household size, the number of dependent members, farm size, agroecological conditions, market access, and ownership of various assets. A detailed list of all variables and how they are measured is provided in Table A1 in the Appendix. We are particularly interested in the coefficient β, which indicates the effect of rice-aquaculture adoption on dietary diversity.

The same type of models as shown in equation (1) are also estimated with time allocation, various income sources, and farm production diversity indicators as dependent variables to analyze potential impact mechanisms.

We are also interested in understanding whether the effects of aquaculture adoption vary for different types of households. To examine heterogenous effects, we re-estimate the models in equation (1) for various subsamples. To understand the role of education, we divide the total sample into low-education and high-education households by using mean years of schooling as the threshold. Regarding age, we classify households as younger and older households if the age of the household head is below or above the sample mean age. In the same way, we also differentiate between farms with smaller and larger land sizes.

A potential problem in estimating the effects of rice-aquaculture with the models in equation (1) is endogeneity. Households' decision to adopt rice-aquaculture is likely not only determined by observed factors (e.g., land size, education levels) but may also be influenced by unobserved factors (e.g., personal preferences and abilities). If unobserved factors are jointly correlated with rice-aquaculture adoption and the outcome variables, the estimates of the coefficient β would be biased. To control for such bias, we use an instrumental variable (IV) approach. Specifically, we estimate endogenous treatment effect models, considering that our endogenous regressor (rice-aquaculture adoption) is a binary variable. Our instrument is the share of farmers adopting rice-aquaculture in the Upazila. This instrument is correlated with individual rice-aquaculture adoption, as farmers are influenced by what is happening in their surroundings. A larger share of adopters at the Upazila level is positively and significantly associated with individual adoption, as is confirmed by the first-stage regression results shown in Table A2 in the Appendix. We conclude that the instrument is relevant.

A second condition for the instrument to be valid is that it is not correlated with the outcome variables through mechanisms other than individual rice-aquaculture adoption. In principle, the share of adopters at the Upazila level may be influenced by local agroecological and/or infrastructure conditions, which could affect diets through various mechanisms. However, in our models we control for various agroecological and market access conditions and also include district fixed effects to account for unobserved regional factors. We carried out falsification tests, which suggest that our instrument is not significantly correlated with HDDS12 and HDDS9 in the normal season and many of the other outcome variables considered (Table A3 in the Appendix). However, we do find significant correlation between the instrument and several other outcomes, including individual-level dietary diversity scores and farm production diversity. Based on these findings we conclude that our instrument is valid in some of the models but not in all. Unfortunately, we were unable to identify instruments that would pass the validity tests in all models used.

Acknowledging that endogeneity bias may not be fully eliminated with our IV approach, we use a suite of alternative methods to test for the robustness of the estimation results.

Specifically, in addition to using ordinary least squares (OLS), and endogenous treatment effect models, we use propensity score matching (PSM), a control function approach (CFA), and an alternative IV approach with heteroscedasticity-based instruments (Lewbel, 2018). All of these approaches have their limitations, so individual estimates have to be interpreted with some caution. However, the estimates across the different approaches used are fairly similar and support the same general conclusions, thus adding confidence that the main findings are robust. Further details are presented and discussed below.

4. Results and discussion

4.1. Descriptive statistics

Table 1 compares household characteristics between adopters and non-adopters of rice-aquaculture. Note that all households grow rice as their main staple crop, but not all combine rice cultivation with aquaculture. As mentioned above, of the 720 total households in our sample, 157 (22%) have adopted rice-aquaculture while 563 have not. On average, adopters have lower education levels and are less likely to be affected by drought than non-adopters. Adopters also have higher debts than non-adopting households. In terms of living standards, adopting households have higher total incomes and farm incomes per capita than non-adopting households, even though we do not see significant differences in consumption expenditures. For food consumption, expenditures (including the value of home consumption) among adopters are even somewhat lower than among non-adopters.

Table 1. Household characteristics by adoption of rice-aquaculture

Variables	Measurement unit	(1) Full sample	(2) Non-adopters	(3) Rice-aquaculture adopters	(3)- (2)
Household size	Number	4.52	4.48	4.66	0.18
		(1.64)	(1.68)	(1.50)	
Age head	Years	50.09	50.09	50.13	0.04
		(12.16)	(12.43)	(11.19)	
Male head	Dummy	0.96	0.96	0.97	0.01
		(0.20)	(0.20)	(0.18)	
Education head	Years of schooling	5.04	5.25	4.32	-0.93**
		(4.31)	(4.34)	(4.17)	
No. of dependents	Number	1.43	1.41	1.49	0.08
		(1.19)	(1.20)	(1.15)	
Having TV	Dummy	0.34	0.33	0.39	0.06
		(0.48)	(0.47)	(0.49)	
Having motorbike	Dummy	0.14	0.13	0.18	0.06 *
		(0.35)	(0.33)	(0.39)	
Having smartphone	Dummy	0.59	0.60	0.59	0.01
		(0.49)	(0.49)	(0.49)	
Land size	Hectare	0.38	0.37	0.41	0.04
		(0.46)	(0.42)	(0.57)	
Asset value per capita	Thousand BDT	10.77	10.508	11.73	1.241
		(10.90)	(10.61)	(11.84)	
Distance to market	Kilometer	1.94	1.96	1.91	-0.04
		(1.30)	(1.29)	(1.37)	
Flood	Dummy	0.03	0.03	0.01	-0.02
		(0.17)	(0.18)	(0.11)	
Drought	Dummy	0.08	0.09	0.04	-0.05**
		(0.01)	(0.01)	(0.01)	
Total income per capita	Thousand BDT	4.31	4.22	4.62	0.40*
		(0.10)	(0.11)	(0.21)	
Farm income per capita	Thousand BDT	2.28	2.16	2.74	0.58***
		(0.07)	(0.08)	(0.17)	
Off-farm income per capita	Thousand BDT	1.59	1.57	1.68	0.12
		(0.07)	(0.08)	(0.17)	
Total consumption per capita	Thousand BDT	4.13	4.17	3.96	0.21
		(0.08)	(0.09)	(0.14)	
Food consumption per capita	Thousand BDT	1.70	1.73	1.60	-0.13*
		(0 .03)	(0.04)	(0.05)	
Non-food consumption per capita	Thousand BDT	2.42	2.44	2.36	0.08
		(0.06)	(0.08)	(0.11)	
Debt value	Thousand BDT	33.56	27.73	54.46	26.73***
		(2.13)	(1.98)	(6.35)	
No. of observations		720	563	157	

**** p < 0.01, **p < 0.05, * p < 0.1; Standard deviations in parentheses*

Table 2 compares the various dietary diversity indicators between rice-aquaculture adopters and non-adopters. During the normal season, adopters of rice-aquaculture appear to have slightly lower dietary diversity scores than non-adopters, both at household and individual levels, but most of these differences are not statistically significant. Yet, during the lean season, rice-aquaculture adopters have significantly lower dietary diversity than non-adopters. Additional descriptives in Tables A4-A5 in the Appendix show differences in the consumption of specific food groups during both seasons. In the lean season, adopters are less likely to consume roots and tubers, seeds and nuts, eggs, dairy products, vegetables, and fruits, but more likely to consume fish and oils and fats than non-adopters.

Table 2. Dietary diversity indicators by adoption of rice-aquaculture

	Normal season			Lean season		
	(1) Non-adopters	(2) Rice-aquaculture adopters	(2)-(1)	(4) Non-adopters	(5) Rice-aquaculture adopters	(5)-(4)
Household dietary diversity, 12 food groups (HDDS12)	9.66	9.43	-0.22	9.45	9.01	-0.44**
	(1.77)	(1.92)		(1.96)	(2.16)	
Household dietary diversity, 9 food groups (HDDS9)	7.00	6.75	-0.25*	6.97	6.50	-0.47***
	(1. 49)	(1.67)		(1.59)	(1.81)	
Men’s dietary diversity score (MDDS)	3.91	3.75	-0.16	-	-	-
	(1.30)	(1.31)				
Women’s dietary diversity score (WDDS)	3.96	3.78	-0.18	-	-	-
	(1.33)	(1.28)				
Child dietary diversity score (CDDS)	3.92	3.86	-0.06	-	-	-
	(1.23)	(1.16)				

**** p<0.01, ** p<0.05, * p<0.1; Standard deviations in parentheses*

4.2. Effects of rice-aquaculture adoption on household diets

We now present results of the regression models explained in equation (1). We use the IV treatment effect model estimates as our main results (robustness checks with various other approaches are discussed further below). Table 3 shows the estimated effects of rice-aquaculture adoption on household dietary diversity. Columns (1) and (2) refer to the normal season. The results suggest that rice-aquaculture adoption may negatively affect household dietary diversity, although the estimate is statistically significant only for HDDS9. More specifically, rice-aquaculture adoption seems to reduce HDDS9 by 0.54 food groups during the normal season.

Columns (3) and (4) of Table 3 refer to the lean season, where the negative effects of rice-aquaculture adoption on household dietary diversity are more pronounced. Rice-aquaculture adoption reduces HDDS12 and HDDS9 by 1.3 and 1.0 food groups, respectively. These are substantial and highly significant negative effects. During the lean season, food supplies are generally low, as the food stocks from the last harvest are almost exhausted and the next harvest in not yet in. This is the time when many rural households in Bangladesh try to pursue other income-earning activities, including non-farm jobs and seasonal migration (Lain & Brunelin, 2024; Rana & Qaim, 2024; Tojo-Mandaharisoa et al., 2023). Rice-aquaculture systems are actually expected to mitigate seasonal food and income shortfalls, because aquaculture production continues also during the lean season. However, as mentioned, rice-aquaculture systems are labor-intensive. They require frequent and careful observation of the fields also during the lean season. This may hinder household members to pursue other activities, which may explain the negative net effects on dietary diversity. These mechanisms are analyzed in more detail below.

Table 3. Effects of adopting rice-aquaculture on household dietary diversity

	Normal season		Lean season	
	(1) HDDS12	(2) HDDS9	(3) HDDS12	(4) HDDS9
Rice-aquaculture	-0.444	-0.540*	-1.338***	-1.036***
	(0.402)	(0.324)	(0.510)	(0.341)
Household size	0.064	0.071	0.103*	0.103**
	(0.058)	(0.046)	(0.061)	(0.050)
Age head	-0.004	-0.005	-0.008	-0.008
	(0.006)	(0.005)	(0.007)	(0.005)
Male head	0.153	0.251	0.057	0.118
	(0.299)	(0.251)	(0.376)	(0.307)
Education head	0.027	0.025	-0.006	0.002
	(0.018)	(0.015)	(0.021)	(0.017)
No. of dependent	0.119	0.067	-0.000	-0.005
	(0.078)	(0.065)	(0.088)	(0.071)
Having TV	0.166	0.144	0.429***	0.301**
	(0.143)	(0.123)	(0.165)	(0.135)
Having motorbike	-0.003	-0.008	0.084	-0.036
	(0.208)	(0.173)	(0.243)	(0.194)
Having smartphone	0.208	0.238*	0.354**	0.270*
	(0.153)	(0.127)	(0.172)	(0.138)
Distance to market	0.078	0.078*	0.097*	0.086*
	(0.051)	(0.042)	(0.055)	(0.044)
Land size	0.288**	0.282***	0.350**	0.295**
	(0.130)	(0.106)	(0.166)	(0.127)
Asset value per capita (ln)	0.248***	0.181**	0.191*	0.163**
	(0.090)	(0.075)	(0.101)	(0.081)
Flood	-0.133	0.060	-0.115	0.165
	(0.336)	(0.252)	(0.394)	(0.318)
Drought	-0.093	-0.177	0.124	0.052
	(0.199)	(0.169)	(0.237)	(0.184)
Khulna district	-0.272	-0.177	-0.424**	-0.255*
	(0.174)	(0.146)	(0.201)	(0.153)
Satkhira district	0.287	0.326**	-0.117	-0.083
	(0.181)	(0.152)	(0.211)	(0.167)
Constant	6.523***	4.454***	7.392***	5.076***
	(0.860)	(0.719)	(0.960)	(0.782)
Wald chi^2	79.02	95.61	75.93	81.09
p-value	0.00	0.00	0.00	0.00
Obs.	720	720	720	720

**** p < 0.01, **p < 0.05, * p < 0.1; Robust standard errors in parentheses; HDDS12: Household dietary diversity score with 12 food groups considered. HDDS9: Household dietary diversity score with 9 food groups considered. Regression results obtained from endogenous treatment effect models.*

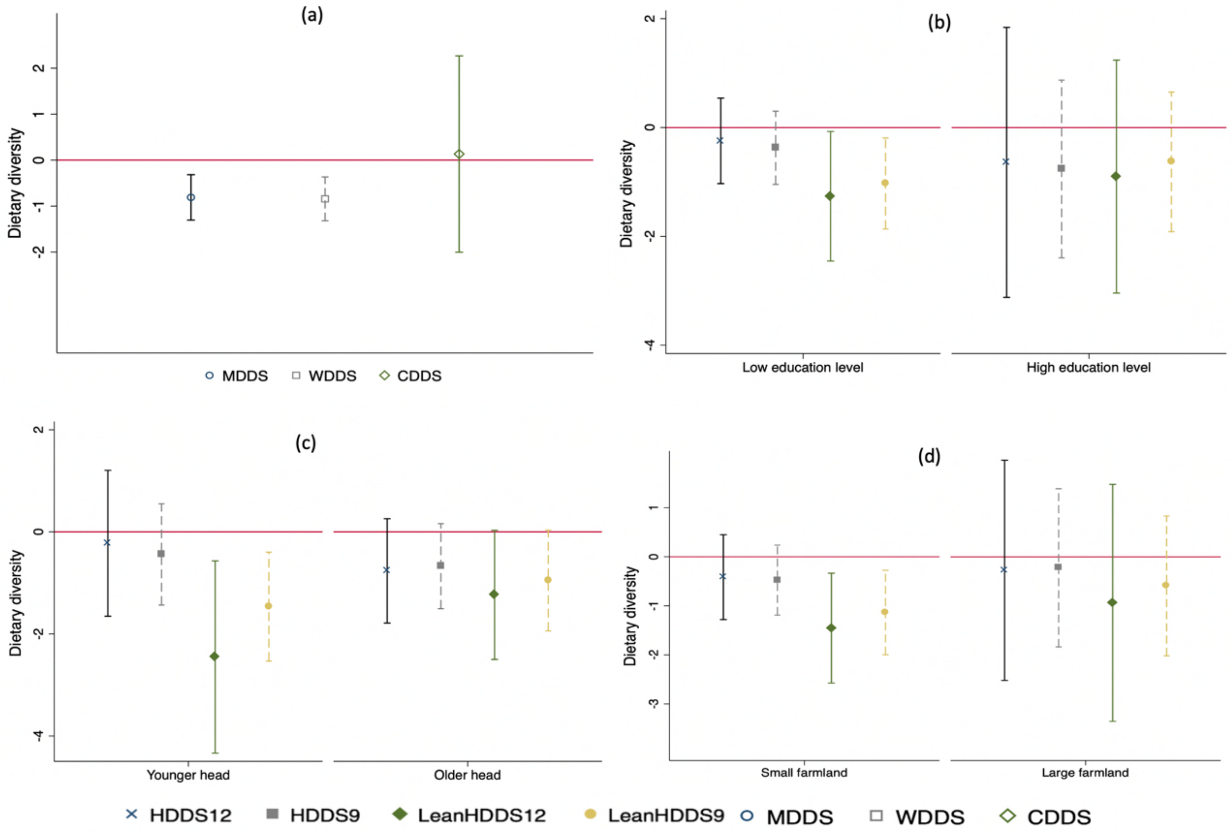

Figure 3. Heterogenous effects of rice-aquaculture adoption
Coefficient estimates from endogenous treatment effect models are shown with 95% confidence intervals. HDDS12: Household dietary diversity score with 12 food groups considered (normal season); HDDS9: Household dietary diversity score with 9 food groups considered (normal season). LeanHDDS12 and Lean HDDS9 refer to household dietary diversity during the lean season. MDDS: Men's dietary diversity score; WDDS: Women's dietary diversity score; CDDS: Child dietary diversity score. Low and high education, young and old household head, and small and large farm subsamples refer to observations below and above sample means for the respective variables. Full models with all control variables are shown in Table A6-A12 in the Appendix.

Figure 3, panel (a) shows the effects of rice-aquaculture adoption on individual-level dietary diversity during the normal season (as mentioned, individual-level diet data were not collected for the lean season). While the effects on child dietary diversity are not statistically significant, adoption seems to have significantly negative effects on men's and women's diets, lowering MDDS and WDDS by almost one food group. The other panels in Figure 3 show the estimation results for the analysis of heterogenous effects on household dietary diversity, again differentiating by season. During the normal season, we do not see statistically significant effects for any of the subsamples, whereas during the lean season we do see significant patterns. Panel (b) reveals that rice-aquaculture adoption has significantly negative effects on lean-season HDDS12 and HDDS9 for households with lower education levels, but not for households with above-average education. This is plausible, as rice-aquaculture systems are knowledge-intensive, and farmers with low education levels may lack the technical knowledge needed for proper management (Islam et al., 2015). Without sufficient technical knowledge and skills in terms of water quality management, fingerling care, and disease and pest control, the economic success of the enterprise may suffer (Islam et al., 2015; Nabi, 2008), contributing to lower instead of better dietary quality for the farming household.

Panel (c) of Figure 3 shows heterogeneous effects for households with younger and older household heads. During the lean season, we observe negative effects on HDDS12 and HDDS9 for both types of households, but the effects are more pronounced for the younger group. This may be related to the fact that younger household heads tend to have smaller households and thus fewer family members who could support the labor-intensive rice-aquaculture business. Also, young household heads tend to have less experience and fewer financial resources for investments into proper technology, which may result in lower productivity and income effects.

Panel (d) of Figure 3 differentiates by land area. Rice-aquaculture adoption has statistically significant negative effects on lean period dietary diversity for small farm households, but not for larger farm households. This may be related to the lower ability of small farm households to invest into proper technology. In addition, the management of rice-aquaculture systems is more challenging on small plots, due to the limited space for both rice and aquaculture production (Dey et al., 2013; Nabi, 2008). In particular, when the fish density is too high, disease pressure increases and rice yields may suffer (Hu et al., 2016).

4.3. Effect mechanisms

We now analyze the mechanisms through which rice-aquaculture adoption may affect dietary diversity. We start with looking at time allocation effects. For this analysis, we sum up the time spent on various activities by male and female adults during the normal and lean season, respectively. Table A13 in the Appendix compares mean values for adopting and non-adopting households.

Figure 4 illustrates the time allocation effects of rice-aquaculture adoption estimated with endogenous treatment effect regression models, controlling for possible confounding factors. The regression results largely confirm the patterns observed in the descriptive statistics. Adopting rice-aquaculture significantly increases household time spent on farm activities and commuting during the lean season. This is expected, as rice-aquaculture systems require frequent field visits for irrigation, disease control, monitoring water levels, and feeding fish. Conversely, adopting rice-aquaculture significantly reduces the time spent on cooking and other domestic activities, both during the lean season and the normal season. With limited time for cooking and domestic activities, households might prefer less diverse calorie-rich meals, which are often quicker to prepare than more diverse and healthy diets. Furthermore, rice-aquaculture adoption significantly reduces the time spent on forest extraction activities during the lean season, including the collection of wild foods and hunting, which may also help explain the negative effects on dietary diversity. Forest extraction activities are much less common during the normal season, when all households are more busy with their own farming activities.

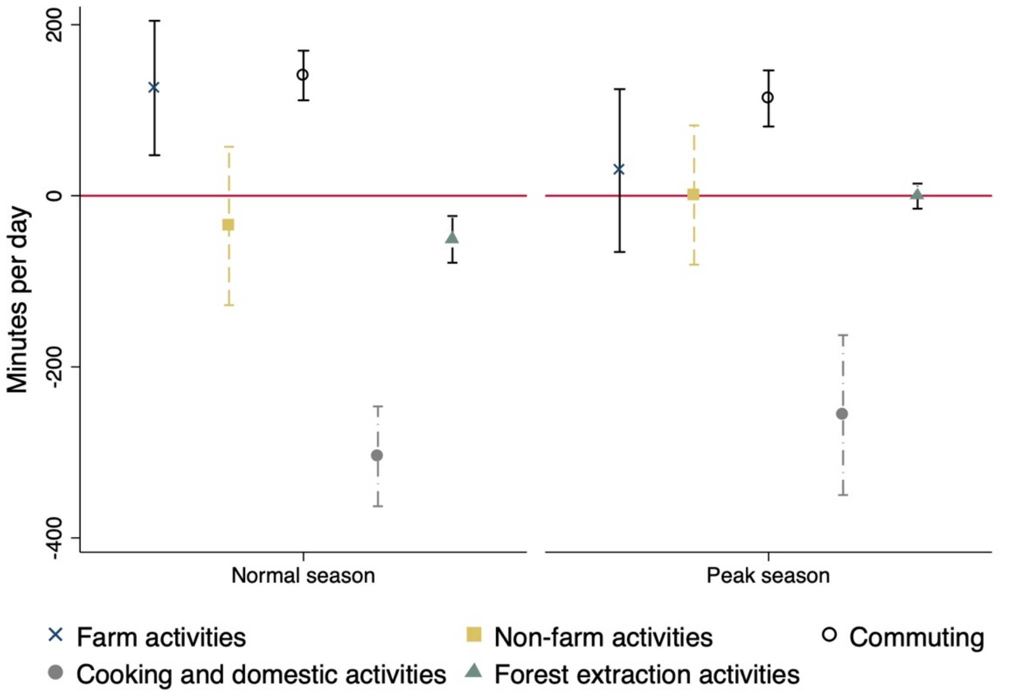

Figure 4. Effects of rice-aquaculture adoption on household time allocation

Coefficient estimates from endogenous treatment effect models are shown with 95% confidence intervals. Full models with all control variables are shown in Tables A14-A15 in the Appendix.

Next, we look at income effects, which are summarized in Figure 5, panel (a). Rice-aquaculture adoption does not seem to significantly affect total per capita income, farm income, and non-farm income. For farm income we would actually have expected a positive effect through the additional aquaculture production in the rice fields, but such a positive effect is not observed. Obviously, the additional time spend on farming is not rewarded by a higher farm income among adopting households. However, rice-aquaculture adoption reduces the income from forest extraction activities, which is plausible, given the lower time spent on this activity during the lean season. In addition, adoption has a slightly negative effect on income from remittances and transfers (including seasonal migration income).

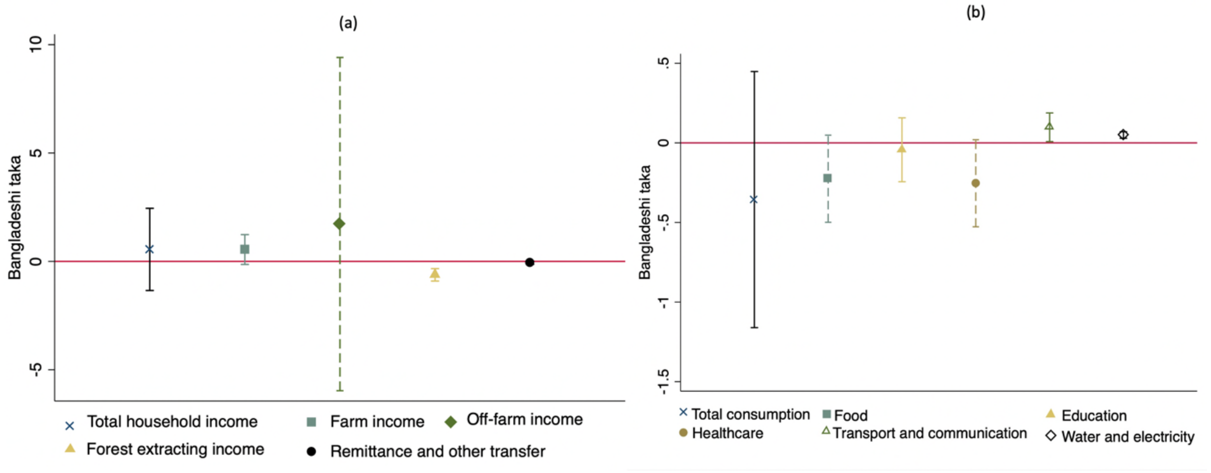

Figure 5. Effects of rice-aquaculture adoption on household income and consumption

Coefficient estimates from endogenous treatment effect models are shown with 95% confidence intervals. Full model results with all control variables included are shown in Tables A16-A17 in the Appendix.

Panel (b) of Figure 5 shows effects of rice-aquaculture adoption on household consumption. The coefficients for total consumption, food consumption, and healthcare expenditures are negative but not statistically significant. However, rice-aquaculture adoption appears to significantly increase the expenditures on transportation and communication, and water and electricity. These effects need to be interpreted with some caution, as some of these items (e.g., water, electricity, transportation) are actually used for aquaculture production rather than for consumption purposes, so they may not indicate an actual increase in household wellbeing.

Finally, we analyze effects of rice-aquaculture adoption on farm production diversity. Descriptive comparisons between adopters and non-adopters are shown in Table A18 in the Appendix. The regression results are summarized in Figure 6. They suggest that rice-aquaculture adoption reduces farm production diversity, which may surprise on first sight, as adoption means additionally introducing aquatic species. Further disaggregation shows that adoption increases the number of aquatic species produced, as expected, but reduces the number of crop and livestock species and therefore also the number of food groups produced by households. This mechanism may also contribute to explaining the negative effect of rice-aquaculture adoption on dietary diversity.

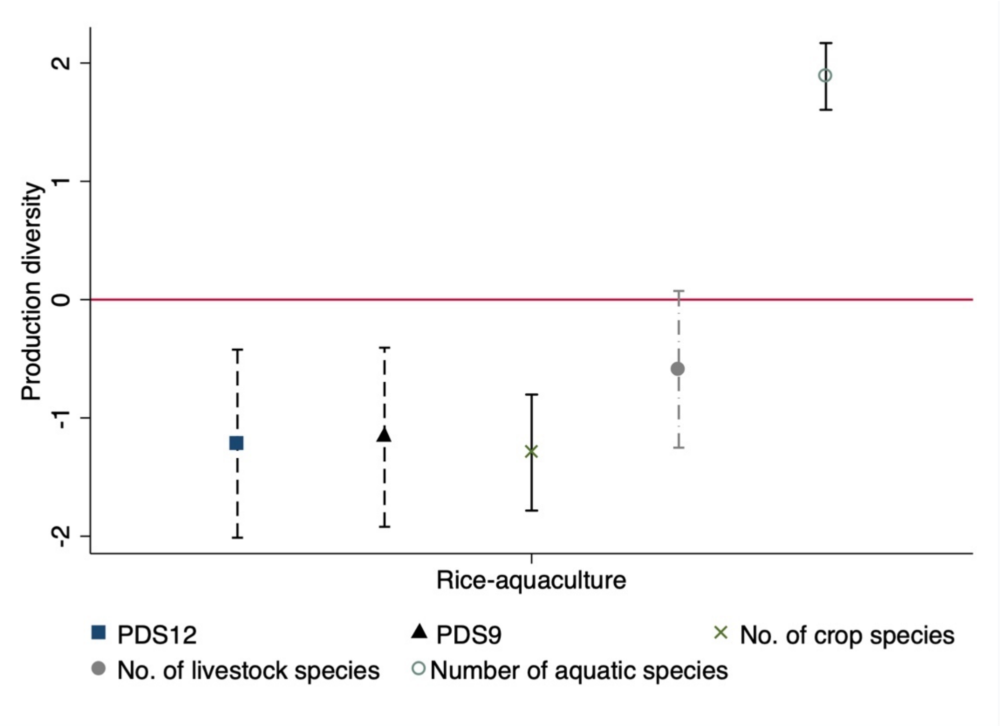

Figure 6. Effects of rice-aquaculture adoption on farm production diversity

Coefficient estimates from endogenous treatment effect models are shown with 95% confidence intervals. PDS12 and PDS9 delineate farm production diversity scores with 12 and 9 food groups considered, respectively. Full model results with all control variables are shown in Table A19 in the Appendix.

4.4. Robustness checks

As explained in the materials and methods section, we also used a suite of alternative econometric approaches to test the robustness of our results. In particular, we used OLS, PSM, CFA, and IV models with heteroscedasticity-based instruments to examine the effects of rice-aquaculture adoption on dietary diversity, time allocation, income and consumption, and farm production diversity. Results obtained from these alternative models are presented in Tables

A20-A31 in the Appendix. Generally, these results are consistent with those from the endogenous treatment effect models presented above.

Rice-aquaculture adoption has negative effects on dietary diversity, and these effects are especially pronounced during the lean season (Table A20). Adoption increases the time spent on farming and commuting, and decreases the time spent on cooking and other domestic activities, and forest extraction (Table A28). In some of the models, adoption has significantly positive effects on farm income, but consistently negative effects on income from forest extraction (Table A29). Adopters spend more on water, electricity, transportation, and communication, whereas effects on total consumption and food consumption are mostly insignificant, and significantly negative in some of the models (Table A30). Rice-aquaculture adoption is positively associated with farm production diversity in models that do not control for unobserved heterogeneity (OLS and PSM), but negatively associated in models with IVs (CFA, heteroscedasticity-based instruments, Table A31). Overall, the main findings seem to be quite robust.

5. Conclusion

5.1. Summary of findings

Rice-aquaculture is widely promoted in many countries as a system to promote land and water productivity and farm nutrient cycling. It is assumed that rice-aquaculture adoption would also improve farm household diets and nutrition by increasing rice yield and providing additional sources of income and food nutrients from aquatic species. However, previous studies analyzing the effects of rice-aquaculture adoption on diets and nutrition do not exist. We have addressed this research gap, using primary data from rice farmers in south-west Bangladesh. We have used different econometric approaches to investigate the effects of rice-aquaculture adoption on dietary quality, measured in terms of household-level and individual-level dietary diversity scores. We have also examined heterogeneous effects for different types of households. Furthermore, we have investigated possible mechanisms of how rice-aquaculture adoption may influence dietary quality, namely through changes in household time allocation, income, and farm production diversity.

Our findings reveal that rice-aquaculture adoption reduces household dietary diversity, women's dietary diversity, and men's dietary diversity, thus contradicting the hypothesis of positive effects on dietary quality. The negative effects are especially pronounced during the lean season, when many rice farmers in Bangladesh experience dietary shortfalls. The hope that these seasonal shortfalls would be mitigated through additionally integrating aquaculture species into the production system is not confirmed in our study. On the contrary, rice-aquaculture adopters are more affected by lean season dietary shortfalls than non-adopters.

The negative dietary effects are primarily due to the large initial financial investments required for adopting rice-aquaculture, limited yield and income gains, and considerable amounts of time needed for managing the system. We show that adoption of rice-aquaculture leads to a significant increase in the household time spent on farming activities and a decrease in the time spent on cooking and other domestic tasks. Especially during the lean season, rice-aquaculture adoption also leads to a decrease in the household time spent on forest extraction activities, such as wild food collection, logging, and hunting. These forest extraction activities are not only a source of off-farm income, but also a source of food diversity, during periods when other income and food sources are scarce. We also show that rice-aquaculture adoption is negatively associated with transfers and remittances, including income from seasonal migration. While rice-aquaculture adoption increases the diversity of aquatic species produced on the farm, it seems to reduce overall farm diversity in terms of other crop and livestock species. Finally, our findings show that rice-aquaculture adopters bear a significantly higher debt burden than non-adopters.

Our results do not imply that rice-aquaculture could not benefit smallholder farmers in general. But in the particular context analyzed here, the economic benefits seem to be small. This is likely due to the complexity of the system, which may be difficult to manage for typical smallholders. This interpretation is supported by our analysis of heterogenous effects: negative diet and nutrition effects of rice-aquaculture adoption are particularly observed among farmers with low education levels, limited experience, and small landholdings. Proper training of farmers and more technical and management support could possibly improve the productivity and income effects and thus also contribute to more healthy and diverse diets.

Our study has a few limitations. First, we have used cross-section observational data, which has drawbacks for the rigorous identification of causal effects. We have employed different approaches to control for possible selection bias resulting from observed and unobserved heterogeneity. All approaches support the same general conclusions, which is reassuring. Nevertheless, we cannot rule out a certain endogeneity bias, meaning that the concrete estimates should be interpreted with some caution. Moreover, cross-sectional data do not allow us to analyze possible dynamics of adoption effects, such as increasing benefits over time due to farmers gaining additional experience. Longitudinal data could provide a more comprehensive understanding. Second, we have tried to differentiate between normal season and lean season effects, which seems to be important, but our lean season data were collected through recall questions and may therefore be associated with inaccuracies. Repeated surveys during different seasons could lead to more reliable estimates. Third, we have used dietary diversity scores as proxies of dietary quality. Additional data on food quantities consumed could help to construct additional indicators of dietary quality, such as nutrient adequacy ratios for various micro- and macronutrients. Follow-up research with more comprehensive data will be useful to gain additional insights into the nutrition effects of rice-aquaculture adoption and the underlying mechanisms.

5.2. Policy implications

Based on the findings, a few policy implications shall now be discussed. Rice-aquaculture systems are complex and time-intensive to manage. Adoption cannot be assumed to improve household incomes and diets in all situations. If not properly managed, rice-aquaculture adoption may even lower dietary quality, as it draws away household time from other economic activities and domestic tasks. The additional on-farm time requirements for managing rice-aquaculture are not a problem per se, if the rice-aquaculture enterprise is more lucrative than the alternative time uses, such as forest extraction activities during agricultural lean seasons. Reducing farmers' forest extraction activities may even be desirable from an environmental perspective because the mangrove forests in south-west Bangladesh are overexploited anyway. However, for smallholder farmers in the region, rice-aquaculture adoption is not yet sufficiently lucrative to offset the opportunity cost of household labor time.

The best option to address this issue and increase farmers' productivity and income gains from rice-aquaculture adoption is to provide better training and technical support. Successfully growing rice and raising fish simultaneously in the same fields needs special knowledge and technical skills (Ahmed & Garnett, 2011; Dey et al., 2013; Samaddar et al., 2025). Training should be provided by the agricultural extension system, possibly in cooperation with local NGOs. Cost-effective extension models to reach a larger number of farmers will need to be developed. These should be designed in gender-sensitive and gender-transformative ways to strengthen the role of women in income-generation. Training of farmer groups could help reduce extension costs. Farmer collective action in terms of investments, input procurement, labor supply, and marketing could also contribute to efficiency gains and mutual learning, thus making rice-aquaculture farming more profitable for smallholders. Combining agricultural training and extension with nutrition education may also be useful to improve dietary quality.

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Appendix

Rice-aquaculture systems and dietary quality in Bangladesh

Table A1. Name and definition of control variables

Name	Measurement unit	Definition
Rice- aquaculture	Dummy (1=yes, 0=otherwise)	Household has adopted the farming system which rice and aquatic species are grown in the same parcel
Household size	Number	Total number of household member
Age head	Years	Age of the household head
Male head	Dummy (1=male, 0=female)	Gender of the household head
Education head	Years	Years of schooling of the household head
No. of dependent	Number	Number of dependent people in the household
Having TV	Dummy (1=yes, 0=no)	Household have a television is =1 and 0 =otherwise
Having motorbike	Dummy (1=yes, 0=no)	Household have a motorbike is =1 and 0 =otherwise
Having smart phone	Dummy (1=yes, 0=no)	Household have a smartphone is =1 and 0 =otherwise
Distance	Kilometer	Distance between house and the local market
Land size	Hectare	Total amount of land owned by the household
District	District dummy1 District dummy2	District dummy 1 (1=Khulna, 0=otherwise) District dummy 2 (1= Satkhira, 0=otherwise)
Flood	Dummy (1=yes, 0=no)	If household experienced flood in last 12 months=1, 0=otherwise
Drought	Dummy (1=yes, 0=no)	If household experienced drought in last 12 months=1, 0=otherwise

Table A2. First-stage regression

Variables	Rice-aquaculture adoption
Household size	0.033
	(0.049)
Age head	-0.007
	(0.005)
Male head	0.124
	(0.313)
Years of school of head	-0.050***
	(0.015)
No. of dependent	-0.008
	(0.066)
Having TV	0.192
	(0.129)
Having motorbike	0.303
	(0.186)
Having smartphone	0.045
	(0.132)
Distance to market	0.008
	(0.044)
Land size	0.257**
	(0.126)
Asset value per capita	0.056
	(0.075)
Flood	-0.324
	(0.427)
Drought	-0.232
	(0.238)
Khulna district	0.113
	(0.183)
Satkhira district	0.030
	(0.189)
Share of rice-aquaculture adoption in the Upazila	0.039***
	(0.005)
Constant	-2.192***
	(0.753)
Observations	720

**** p<0.01, ** p<0.05, * p<0.1; Robust standard errors in parentheses*

Table A3. Falsification test

List of dependent/outcome variables	Share of rice-aquaculture adoption in the Upazila	Robust standard error
HDDS12	-0.007	(0.006)
HDDS9	-0.009	(0.005)
HDDS12 lean	-0.016**	(0.007)
HDDS9 lean	-0.015***	(0.006)
MDDS	-0.010**	(0.004)
WDDS	-0.009**	(0.004)
CDDS	0.002	(0.006)
Farm activities in normal season	-0.492	(0.733)
Non-farm activities in normal season	0.508	(0.639)
Commuting in normal season	1.441***	(0.274)
Cooking and domestic activities in normal season	-1.066*	(0.599)
Forest extraction activities in normal season	0.091	(0.147)
Other activities in normal season	2.702**	(1.292)
Farm activities in lean season	1.400**	(0.704)
Non-farm activities in lean season	0.199	(0.712)
Commuting in lean season	2.278***	(0.266)
Cooking and domestic activities in lean season	-2.166***	(0.579)
Forest extraction activities in lean season	-1.278***	(0.331)
Other activities in lean season	1.455	(1.401)
PDS12	-0.021***	(0.006)
PDS9	-0.020***	(0.006)
Number of crop species cultivated in normal season	-0.027***	(0.005)
Number of livestock species in normal season	-0.012***	(0.004)
Number of aquatic species in normal season	0.023***	(0.002)
Total income	0.008	(0.009)
Farm income	0.006	(0.006)
Off-farm income	0.014**	(0.007)
Forest extracting income	-0.013***	(0.004)
Remittance, stipend and public transfer	-0.001	(0.001)
Total consumption	-0.008	(0.006)
Food	-0.003	(0.003)
Education	-0.002	(0.002)
Health	-0.006*	(0.004)
Transport and communication	0.000	(0.001)
Water and electricity	0.001***	(0.000)
Other non-food consumption	0.003	(0.002)

**** p<0.01, ** p<0.05, * p<0.1*

Table A4. Different food groups consumption by rice-aquaculture adoption in the normal season

Food groups	(1) Full sample	(2) Non-adopters	(3) Rice-aquaculture adopters	(3)-(2) Difference
Cereals	0 .934	0.948	0.885	-0.063***
	(0.247)	(0.221)	(0.320)	
Roots and tubers	0.837	0.847	0.803	-0.045
	(0.369)	(0.360)	(0.399)	
Eggs	0.868	0.865	0.879	0.014
	(0.339)	(0.342)	(0.327)	
Fish	0.95	0.950	0.949	-0.001
	(0.291)	(0.218)	(0.221)	
Seeds and nuts	0 .805	0.829	0.720	-0.110***
	(0.396)	(0.376)	(0.451)	
Milk and dairy product	0 .405	0.425	0.338	-0.087**
	(0.491)	(0.495)	(0.474)	
Oils and fat	0.9222	0.904	0.987	0.083***
	(0.268)	(0.295)	(0.113)	
Spices and condiments	0.9777	0.975	0.987	0.012
	(0.148)	(0.156)	(0.113)	
Sweets	0.759	0.774	0.707	-0.067*
	(0.427)	(0.418)	(0.457)	
Vegetables	0.990	0.989	0.994	0.004
	(0.981)	(0.103)	(0.080)	
Fruits	0.59	0.597	0.599	0.002
	(0.490)	(0.491)	(0.492)	
Meat	0.559	0.552	0.586	0.034
	(0.497	(0.498)	(0.494)	
Observations	720	563	157	

**** p < 0.01, **p < 0.05, * p < 0.1; Standard deviation in parentheses*

Table A5. Different food groups consumption by rice-aquaculture adoption in lean season

Food groups	(1) Full sample	(2) Non-adopters	(3) Rice-aquaculture adopters	(3)-(2) Difference
Cereals	1.00	1.000	1.000	0.000
	(0.000)	(0.000)	(0.000)	
Roots and tubers	0 .801	0.815	0.752	-0.064*
	(0.399)	(0.388)	(0.434)	
Eggs	0 .768	0.801	0.650	-0.151***
	(0.422)	(0.400)	(0.479)	
Fish	0.936	0.927	0.968	0.041*
	(0.244)	(0.260)	(0.176)	
Seeds and nuts	0.722	0.760	0.586	-0.174***
	(0.448)	(0.427)	(0.494)	
Milk and dairy product	0.418	0.439	0.344	-0.095**
	(0.494)	(0.497)	(0.477	
Oils and fat	0.923	0.902	1.000	0.098***
	(0.266)	(0.297)	(0.000)	
Spices and condiments	0.927	0.927	0.930	0.003
	(0.259)	(0.260)	(0.256)	
Sweets	0.637	0.654	0.580	-0.074*
	(0.481)	(0.476)	(0.495)	
Vegetables	0.983	0.988	0.968	-0.019*
	(0.128)	(0.111)	(0.176)	
Fruits	0 .714	0.732	0.650	-0.082**
	(0.452)	(0.443)	(0.479)	
Meat	0.525	0.510	0.580	0.070
	(0.500)	(0.500)	(0.495)	
Observations	720	563	157	

**** p < 0.01, **p < 0.05, * p < 0.1; Standard deviation in parentheses*

Table A6. Effects of rice-aquaculture adoption on individual dietary diversity

	(1)	(2)	(3)
	MDDS	WDDS	CDDS
Rice-aquaculture	-0.811***	-0.843***	0.132
	(0.252)	(0.243)	(1.090)
Household size	-0.066	-0.122**	-0.159**
	(0.041)	(0.048)	(0.080)
Age head	0.006	0.004	0.006
	(0.004)	(0.004)	(0.008)
Male head	0.009	0.243	-0.500*
	(0.265)	(0.258)	(0.298)
Education head	0.102*	0.068	0.070
	(0.053)	(0.054)	(0.085)
No. of dependent	-0.004	0.100*	0.138*
	(0.054)	(0.057)	(0.080)
Having TV	-0.028	0.136	0.451***
	(0.111)	(0.113)	(0.150)
Having motorbike	0.169	0.170	0.156
	(0.150)	(0.166)	(0.286)
Having smartphone	0.190*	0.219*	0.007
	(0.110)	(0.117)	(0.178)
Distance to market	0.099***	0.084**	0.004
	(0.036)	(0.035)	(0.052)
Land size	0.295***	0.260**	0.215
	(0.098)	(0.113)	(0.187)
Asset value per capita (ln)	0.041	0.058	0.032
	(0.063)	(0.067)	(0.094)
Flood	-0.365	-0.197	-0.300
	(0.280)	(0.281)	(0.355)
Drought	0.001	-0.244	0.235
	(0.192)	(0.188)	(0.300)
Khulna district	0.134	-0.020	-1.070***
	(0.130)	(0.139)	(0.363)
Satkhira district	1.089***	0.890***	0.171
	(0.133)	(0.144)	(0.282)
Constant	2.695***	2.694***	4.199***
	(0.642)	(0.649)	(0.833)
Wald chi^2	188.45	192.81	126.81
p-value	0.00	0.00	0.00
Observations	701	693	267

**** p<0.01, ** p<0.05, * p<0.1; Robust standard errors in parentheses*

Table A7. Effects of rice-aquaculture adoption on farmers with low education levels

	Normal season			Lean season
	(1)	(2)	(3)	(4)
	HDDS12	HDDS9	HDDS12	HDDS9
Rice-aquaculture	-0.245	-0.371	-1.263**	-1.028**
	(0.401)	(0.343)	(0.608)	(0.428)
Household size	0.083	0.086	0.068	0.079
	(0.075)	(0.061)	(0.080)	(0.064)
Age head	-0.008	-0.010	-0.011	-0.010
	(0.008)	(0.007)	(0.009)	(0.007)
Male head	0.418	0.540*	0.623	0.615
	(0.355)	(0.297)	(0.550)	(0.435)
No. of dependent	0.193*	0.127	0.069	0.064
	(0.100)	(0.085)	(0.116)	(0.094)
Having TV	0.094	0.132	0.319	0.186
	(0.180)	(0.157)	(0.223)	(0.181)
Having motorbike	-0.195	-0.228	0.013	-0.124
	(0.328)	(0.272)	(0.395)	(0.317)
Having smartphone	0.077	0.170	0.158	0.165
	(0.177)	(0.151)	(0.214)	(0.172)
Distance to market	0.048	0.062	0.056	0.053
	(0.068)	(0.055)	(0.075)	(0.060)
Land size	0.198	0.297*	-0.091	-0.029
	(0.220)	(0.172)	(0.292)	(0.216)
Asset value per capita (ln)	0.309***	0.230**	0.184	0.164
	(0.104)	(0.090)	(0.126)	(0.101)
Flood	-0.271	-0.138	-0.207	0.160
	(0.514)	(0.416)	(0.638)	(0.527)
Drought	-0.209	-0.271	0.207	0.097
	(0.285)	(0.256)	(0.323)	(0.262)
Khulna district	-0.477**	-0.298	-0.485*	-0.256
	(0.225)	(0.191)	(0.274)	(0.208)
Satkhira district	0.124	0.235	-0.012	0.035
	(0.213)	(0.184)	(0.259)	(0.203)
Constant	6.142***	4.042***	7.424***	4.903***
	(1.072)	(0.906)	(1.300)	(1.035)
Wald chi^2	44.54	55.49	34.45	34.60
p-value	0.00	0.00	0.00	0.00
Observations	437	437	437	437

**** p < 0.01, **p < 0.05, * p < 0.1; Robust standard errors in parentheses.*

Table A8. Effects of rice-aquaculture adoption on farmers with high education levels

	Normal season		Lean season	
	(1)	(2)	(3)	(4)
	HDDS12	HDDS9	HDDS12	HDDS9
Rice-aquaculture	-0.640	-0.762	-0.902	-0.630
	(1.266)	(0.833)	(1.092)	(0.654)
Household size	0.020	0.037	0.187*	0.159**
	(0.092)	(0.074)	(0.097)	(0.078)
Age head	0.003	0.001	-0.002	-0.007
	(0.009)	(0.007)	(0.009)	(0.007)
Male head	-0.210	-0.129	-0.743	-0.512
	(0.564)	(0.455)	(0.470)	(0.387)
No. of dependent	0.037	0.001	-0.119	-0.116
	(0.129)	(0.105)	(0.131)	(0.104)
Having TV	0.183	0.121	0.415*	0.344*
	(0.235)	(0.199)	(0.241)	(0.201)
Having motorbike	0.153	0.184	0.063	-0.025
	(0.301)	(0.241)	(0.310)	(0.246)
Having smartphone	0.517*	0.431*	0.769***	0.503**
	(0.287)	(0.233)	(0.281)	(0.231)
Distance to market	0.121	0.106	0.145*	0.117*
	(0.086)	(0.071)	(0.084)	(0.068)
Land size	0.400**	0.346**	0.455**	0.386**
	(0.200)	(0.155)	(0.211)	(0.159)
Asset value per capita (ln)	0.219	0.152	0.288*	0.246*
	(0.164)	(0.135)	(0.157)	(0.130)
Flood	0.116	0.324	0.198	0.325
	(0.502)	(0.310)	(0.513)	(0.366)
Drought	0.070	-0.038	0.023	-0.017
	(0.273)	(0.220)	(0.348)	(0.266)
Khulna district	0.081	0.068	-0.393	-0.319
	(0.307)	(0.246)	(0.312)	(0.231)
Satkhira district	0.531	0.466*	-0.444	-0.414
	(0.339)	(0.269)	(0.352)	(0.279)
Constant	6.745***	4.852***	6.281***	4.511***
	(1.487)	(1.219)	(1.475)	(1.208)
Wald chi^2	41.29	42.54	70.61	68.05
p-value	0.00	0.00	0.00	0.00
Observations	283	283	283	283

**** p < 0.01, **p < 0.05, * p < 0.1; Robust standard errors in parentheses.*

Table A9. Effects of rice-aquaculture adoption on households with younger heads

	Normal season		Lean season	
	(1)	(2)	(3)	(4)
	HDDS12	HDDS9	HDDS12	HDDS9
Rice-aquaculture	0.024	-0.308	-1.587	-1.110**
	(0.578)	(0.450)	(1.175)	(0.483)
Household size	-0.010	0.002	-0.011	-0.003
	(0.096)	(0.079)	(0.111)	(0.085)
Male head	0.266	0.266	0.152	0.202
	(0.383)	(0.316)	(0.470)	(0.388)
Education head	0.172*	0.143*	0.020	0.059
	(0.097)	(0.078)	(0.127)	(0.089)
No. of dependent	0.157	0.124	0.073	0.051
	(0.111)	(0.094)	(0.128)	(0.097)
Having TV	0.222	0.241	0.480**	0.399**
	(0.200)	(0.166)	(0.241)	(0.186)
Having motorbike	0.266	0.208	0.149	0.005
	(0.262)	(0.218)	(0.324)	(0.257)
Having smart Phone	0.261	0.237	0.490**	0.310*
	(0.206)	(0.169)	(0.230)	(0.179)
Distance to market	-0.038	0.002	-0.064	-0.024
	(0.072)	(0.056)	(0.080)	(0.060)
Land size	0.344**	0.301**	0.492***	0.462***
	(0.141)	(0.122)	(0.191)	(0.143)
Asset value per capita (ln)	0.115	0.094	0.013	0.020
	(0.116)	(0.099)	(0.138)	(0.111)
Flood	-0.774	-0.568	-0.035	0.419
	(0.577)	(0.440)	(0.763)	(0.459)
Drought	-0.384	-0.414*	-0.332	-0.303
	(0.318)	(0.251)	(0.406)	(0.304)
Khulna district	-0.315	-0.201	-0.200	-0.169
	(0.248)	(0.201)	(0.357)	(0.221)
Satkhira district	0.601**	0.570***	0.154	0.077
	(0.245)	(0.207)	(0.312)	(0.226)
Constant	7.613***	5.168***	8.939***	6.277***
	(1.139)	(0.957)	(1.299)	(1.073)
Wald chi^2	43.15	81.22	34.28	43.86
p-value	0.00	0.00	0.00	0.00
Observations	360	360	360	360

**** p < 0.01, **p < 0.05, * p < 0.1; Robust standard errors in parentheses.*

Table A10. Effects of rice-aquaculture adoption on households with older heads

	Normal season		Lean season	
	(1)	(2)	(3)	(4)
	HDDS12	HDDS9	HDDS12	HDDS9
Rice-aquaculture	-0.717	-0.708	-1.175*	-0.929*
	(0.532)	(0.437)	(0.612)	(0.475)
Household size	0.114	0.117**	0.152*	0.150**
	(0.074)	(0.060)	(0.080)	(0.065)
Male head	-0.059	0.330	-0.204	-0.102
	(0.413)	(0.388)	(0.620)	(0.413)
Education head	0.046	0.079	-0.124	-0.072
	(0.114)	(0.094)	(0.121)	(0.100)
No. of dependent	0.037	-0.025	-0.052	-0.048
	(0.115)	(0.098)	(0.134)	(0.109)
Having TV	0.134	0.066	0.430*	0.245
	(0.206)	(0.180)	(0.232)	(0.195)
Having motorbike	-0.185	-0.165	0.112	-0.009
	(0.336)	(0.284)	(0.371)	(0.297)
Having smart Phone	0.123	0.239	0.173	0.194
	(0.233)	(0.194)	(0.264)	(0.220)
Distance to market	0.191***	0.153**	0.237***	0.179***
	(0.072)	(0.062)	(0.076)	(0.062)
Land size	0.329	0.340*	0.227	0.134
	(0.218)	(0.177)	(0.272)	(0.211)
Asset value per capita (ln)	0.341**	0.224**	0.333**	0.279**
	(0.136)	(0.113)	(0.144)	(0.120)
Flood	0.274	0.438	-0.260	-0.042
	(0.417)	(0.293)	(0.471)	(0.416)
Drought	0.089	-0.015	0.340	0.218
	(0.254)	(0.225)	(0.301)	(0.234)
Khulna district	-0.258	-0.141	-0.625**	-0.352*
	(0.252)	(0.214)	(0.264)	(0.212)
Satkhira district	-0.020	0.110	-0.428	-0.281
	(0.265)	(0.220)	(0.286)	(0.238)
Constant	5.605***	3.566***	5.875***	3.714***
	(1.154)	(0.985)	(1.297)	(1.032)
Wald chi^2	75.93	58.02	65.72	64.47
p-value	0.00	0.00	0.00	0.00
Observations	360	360	360	360

**** p < 0.01, **p < 0.05, * p < 0.1; Robust standard errors in parentheses.*

Table A11. Effects of rice-aquaculture adoption on households with smaller farmland area

	Normal season		Lean season	
	(1)	(2)	(3)	(4)
	HDDS12	HDDS9	HDDS12	HDDS9
Rice-aquaculture	-0.415	-0.476	-1.455**	-1.136***
	(0.441)	(0.364)	(0.571)	(0.439)
Household size	0.148*	0.123*	0.128	0.107
	(0.079)	(0.067)	(0.087)	(0.072)
Age head	-0.009	-0.008	-0.014	-0.012
	(0.008)	(0.007)	(0.009)	(0.007)
Male head	-0.004	0.152	0.396	0.375
	(0.390)	(0.327)	(0.476)	(0.376)
Education head	0.029	0.061	-0.182	-0.124
	(0.106)	(0.087)	(0.122)	(0.099)
No. of dependent	0.105	0.072	-0.017	-0.007
	(0.100)	(0.086)	(0.113)	(0.094)
Having TV	0.259	0.232	0.442**	0.325*
	(0.173)	(0.150)	(0.204)	(0.169)
Having motorbike	0.010	0.026	-0.062	-0.124
	(0.284)	(0.236)	(0.323)	(0.260)
Having smart Phone	-0.001	0.120	0.218	0.216
	(0.174)	(0.148)	(0.202)	(0.166)
Distance to market	0.148**	0.131**	0.132*	0.122**
	(0.066)	(0.054)	(0.072)	(0.057)
Asset value per capita (ln)	0.259**	0.188**	0.218*	0.192*
	(0.109)	(0.093)	(0.122)	(0.104)
Flood	-0.463	-0.284	0.148	0.290
	(0.460)	(0.335)	(0.561)	(0.449)
Drought	0.073	-0.029	0.306	0.256
	(0.268)	(0.237)	(0.322)	(0.259)
Khulna district	-0.418*	-0.273	-0.614**	-0.301
	(0.219)	(0.181)	(0.257)	(0.203)
Satkhira district	0.146	0.245	-0.165	-0.040
	(0.219)	(0.184)	(0.255)	(0.207)
Constant	6.612***	4.425***	7.348***	4.823***
	(1.095)	(0.935)	(1.233)	(1.028)
Wald chi^2	73.69	53.86	50.23	46.23
p-value	0.00	0.00	0.00	0.00
Observations	475	475	475	475

**** p < 0.01, **p < 0.05, * p < 0.1; Robust standard errors in parentheses.*

Table A12. Effects of rice-aquaculture adoption on households with large farmland area

	Normal season		Lean season	
	(1)	(2)	(3)	(4)
	HDDS12	HDDS9	HDDS12	HDDS9
Rice-aquaculture	-0.518	-0.484	-0.959	-0.729
	(0.763)	(0.548)	(0.822)	(0.485)
Household size	-0.030	0.017	0.076	0.096
	(0.079)	(0.060)	(0.087)	(0.069)
Age head	0.007	0.002	-0.003	-0.008
	(0.009)	(0.007)	(0.010)	(0.008)
Male head	0.461	0.428	-0.810	-0.577
	(0.438)	(0.302)	(0.709)	(0.604)
Education head	0.233**	0.182**	0.169	0.142
	(0.105)	(0.084)	(0.123)	(0.096)
No. of dependent	0.127	0.053	0.038	0.021
	(0.118)	(0.096)	(0.136)	(0.105)
Having TV	-0.123	-0.100	0.126	0.067
	(0.258)	(0.220)	(0.276)	(0.222)
Having motorbike	0.241	0.106	0.586	0.324
	(0.337)	(0.275)	(0.395)	(0.304)
Having smart Phone	0.742**	0.536**	0.802***	0.474**
	(0.288)	(0.234)	(0.311)	(0.241)
Distance to market	-0.027	0.010	0.033	0.030
	(0.079)	(0.067)	(0.086)	(0.070)
Asset value per capita (ln)	0.237	0.188	0.161	0.145
	(0.148)	(0.121)	(0.171)	(0.127)
Flood	0.396	0.568**	-0.293	0.111
	(0.421)	(0.256)	(0.532)	(0.413)
Drought	-0.384	-0.416*	-0.085	-0.200
	(0.289)	(0.225)	(0.346)	(0.256)
Khulna district	-0.066	-0.054	-0.228	-0.224
	(0.277)	(0.232)	(0.301)	(0.225)
Satkhira district	0.336	0.337	-0.367	-0.350
	(0.312)	(0.258)	(0.366)	(0.291)
Constant	6.123***	4.234***	8.054***	6.015***
	(1.353)	(1.094)	(1.625)	(1.270)
Wald chi^2	58.05	73.69	36.82	33.05
p-value	0.00	0.00	0.00	0.00
Observations	245	245	245	245

**** $p < 0.01$, **$p < 0.05$, * $p < 0.1$; Robust standard errors in parentheses.*

Table A13. Time allocation indicators by rice-aquaculture adoption

	(1) Full sample	(2) Non-adopters	(3) Rice-aquaculture adopters	(3)-(2) Difference
Panel A: Normal season				
Farm activities	368.645	350.409	434.045	83.636***
	(212.150)	(194.918)	255.072	
Non-farm activities	90.00	87.469	99.076	11.608
	(189.157)	(186.303)	199.408	
Commuting	111.167	105.346	132.038	26.692***
	(79.357)	(79.066)	77.095	
Cooking and domestic activities	409.812	422.185	365.446	-56.739***
	(192.016)	(198.871)	157.863	
Forest extraction activities	4.583	4.689	4.204	-0.485
	(49.861)	(49.786)	50.292	
Other activities	1161.75	1164.805	1150.796	-14.008
	(399.460)	(410.306)	358.884	
Panel B: Lean season				
Farm activities	234.291	211.838	314.809	102.971***
	(206.078)	(185.342)	(252.265)	
Non-farm activities	111.708	112.380	109.299	-3.081
	(210.844)	(214.044)	(199.591)	
Commuting	101.104	91.412	135.860	44.448***
	(79.164)	(74.888)	(84.414)	
Cooking and domestic activities	405.604	422.078	346.529	-75.549***
	(192.214)	(199.182)	(151.218)	
Forest extraction activities	16.770	19.769	6.019	-13.750*
	(92.101)	(100.061)	(53.651)	
Other activities	1286.5	1289.414	1276.051	-13.363
	(436.01)	(450.119)	(382.265)	

**** p < 0.01, **p < 0.05, * p < 0.1; Standard deviations in parentheses*

Table A14. Effects of rice-aquaculture adoption on time use during the lean season

	(1)	(2)	(3)	(4)	(5)	(6)
	Farm activities	Non-farm activities	Commuting	Cooking & domestic activities	Forest extraction activities	Other activities
Rice-aquaculture	125.940***	-35.390	140.594***	-304.621***	-50.932***	176.157**
	(40.080)	(47.218)	(14.802)	(29.777)	(13.944)	(83.038)
Household size	-2.655	14.917**	9.630***	12.350	0.132	31.759*
	(6.664)	(7.345)	(2.931)	(7.916)	(2.582)	(19.231)
Age head	-0.411	0.280	-0.154	-2.429***	-0.927**	-7.401***
	(0.618)	(0.760)	(0.283)	(0.704)	(0.367)	(1.683)
Male head	-10.162	-26.024	11.033	194.544***	26.715***	296.544***
	(43.255)	(41.397)	(15.654)	(37.279)	(8.375)	(108.134)
Education head	-1.502	2.730	1.010	-6.768***	-2.076**	-2.693
	(1.974)	(2.303)	(0.877)	(2.086)	(0.998)	(4.496)
No. of dependent	-13.880	1.079	-9.497**	-26.814***	1.144	-32.871
	(8.771)	(9.634)	(4.057)	(9.798)	(4.267)	(21.844)
Having TV	-10.881	22.397	-20.423***	17.383	-8.661	-27.613
	(17.038)	(18.025)	(7.235)	(17.788)	(6.446)	(37.231)
Having motorbike	1.966	27.655	-1.811	-4.871	21.322	45.673
	(24.370)	(27.790)	(11.057)	(26.721)	(13.771)	(48.329)
Having smartphone	-5.632	-4.843	8.680	15.099	1.445	30.182
	(17.928)	(18.143)	(7.333)	(18.222)	(8.016)	(37.681)
Distance to market	6.756	-2.764	-5.572**	-1.634	1.775	-11.772
	(5.469)	(5.692)	(2.334)	(5.874)	(2.623)	(13.004)
Land size	28.353	-18.170	-8.050	18.567	-10.742*	-47.823
	(20.330)	(15.365)	(7.498)	(18.498)	(5.595)	(35.901)
Asset value per capita (ln)	-12.190	10.333	3.106	-2.955	6.756*	-11.862
	(10.590)	(10.079)	(4.253)	(10.113)	(4.003)	(20.477)
Flood	-45.455	158.500***	-10.383	-59.329	-13.996**	-72.921
	(43.433)	(55.636)	(17.121)	(51.332)	(6.836)	(94.803)
Drought	1.141	29.457	12.604	-10.957	-15.565	16.481
	(23.783)	(32.355)	(11.545)	(26.859)	(9.758)	(58.570)
Khulna district	-11.505	-51.117**	-0.062	81.156***	-17.169*	23.664
	(19.491)	(22.480)	(8.024)	(21.446)	(10.267)	(48.093)
Satkhira district	86.384***	-42.370*	-4.652	61.247***	-34.525***	-79.270
	(21.288)	(23.402)	(8.433)	(22.217)	(10.961)	(49.412)
Constant	341.753***	-11.961	22.039	380.605***	17.788	1,402.570***
	(105.323)	(99.139)	(40.825)	(96.507)	(44.983)	(221.819)
Wald chi^2	55.59	42.85	168.00	149.89	24.27	50.61
p-value	0.00	0.00	0.00	0.00	0.08	0.00
Observations	720	720	720	720	720	720

**** $p < 0.01$, **$p < 0.05$, * $p < 0.1$, Robust standard errors in parentheses*

Table A15. Effects of rice-aquaculture adoption on time use during the normal season

	(1) Farm activities	(2) Non-farm activities	(3) Commuting	(4) Cooking & domestic activities	(5) Forest extraction activities	(6) Other activities
Rice-aquaculture	29.489	0.868	113.725***	-256.390***	-0.428	196.563***
	(48.563)	(41.540)	(16.727)	(47.685)	(7.483)	(71.256)
Household size	6.318	7.049	8.320***	7.583	0.804	36.219**
	(7.424)	(6.568)	(2.861)	(7.678)	(1.208)	(17.940)
Age head	-3.087***	0.783	-0.208	-3.275***	-0.084	-4.265***
	(0.681)	(0.737)	(0.276)	(0.710)	(0.133)	(1.585)
Male head	46.333	-6.287	3.462	193.278***	6.344*	232.942**
	(48.646)	(28.137)	(17.098)	(37.794)	(3.330)	(113.453)
Education head	-8.506***	5.207**	1.084	-7.300***	-0.835	2.139
	(2.123)	(2.043)	(0.868)	(2.209)	(0.612)	(4.246)
No. of dependent	-28.854***	7.985	-8.396**	-18.257*	-1.496	-33.219*
	(9.105)	(8.828)	(4.021)	(9.505)	(1.991)	(20.010)
Having TV	28.194*	10.510	-14.680**	20.956	-3.565	-63.478*
	(17.026)	(16.049)	(7.286)	(17.039)	(4.126)	(34.006)
Having motorbike	3.187	32.094	-11.219	-6.728	-8.462**	57.257
	(24.756)	(25.585)	(10.676)	(25.188)	(3.485)	(44.636)
Having smartphone	1.057	4.408	7.367	15.236	1.556	18.764
	(17.596)	(16.085)	(7.233)	(18.055)	(4.390)	(35.084)
Distance to market	3.000	-2.185	-5.162**	-0.190	1.973	-8.790
	(5.765)	(5.114)	(2.360)	(5.782)	(1.958)	(12.021)
Land size	30.302*	-17.077	-7.797	11.818	-4.503	-44.378
	(17.576)	(13.958)	(7.843)	(18.099)	(3.287)	(34.989)
Asset value per capita (ln)	-13.463	13.034	8.908**	-7.973	5.209**	-15.696
	(10.924)	(8.855)	(4.188)	(10.151)	(2.306)	(19.258)
Flood	20.882	56.754	-5.772	-73.304	-2.758	-6.514
	(50.222)	(48.238)	(17.383)	(45.690)	(2.173)	(87.977)
Drought	2.361	3.992	1.776	0.265	-6.436**	36.590
	(26.212)	(27.411)	(11.682)	(27.462)	(3.016)	(52.930)
Khulna district	-18.942	-64.429***	8.031	61.658***	-7.163	58.014
	(21.229)	(20.891)	(8.292)	(22.381)	(7.594)	(43.657)
Satkhira district	90.038***	-48.873**	-1.741	52.046**	-14.422*	-65.406
	(22.355)	(21.011)	(8.783)	(21.779)	(7.448)	(44.841)
Constant	592.966***	-87.391	-3.557	483.307***	-32.566**	1,155.644***
	(106.200)	(87.477)	(41.904)	(94.870)	(15.280)	(215.572)
Wald chi^2	94.74	44.39	98.12	79.24	7.64	46.22
p-value	0.00	0.00	0.00	0.00	0.95	0.00
Observations	720	720	720	720	720	720

**** $p < 0.01$, **$p < 0.05$, * $p < 0.1$, Robust standard errors in parentheses*

Table A16. Effects of rice-aquaculture adoption on households' per capita monthly income

	(1)	(2)	(3)	(4)	(5)
	Total income	Farm income	Off-farm income	Forest extracting income	Remittance, stipends and transfers
Rice-aquaculture	0.551	0.546	1.720	-0.621***	-0.066*
	(0.967)	(0.351)	(3.923)	(0.146)	(0.035)
Household size	-0.235**	-0.361***	0.168	-0.052	-0.008
	(0.112)	(0.064)	(0.103)	(0.042)	(0.007)
Age head	0.014	-0.002	0.019**	-0.001	0.000
	(0.009)	(0.005)	(0.010)	(0.007)	(0.001)
Male head	0.353	0.200	-0.220	0.341**	-0.177*
	(0.521)	(0.378)	(0.484)	(0.145)	(0.098)
Education head	-0.038	0.003	0.022	-0.048***	-0.000
	(0.033)	(0.019)	(0.062)	(0.018)	(0.003)
No. of dependent	-0.449***	-0.075	-0.357***	-0.015	-0.004
	(0.109)	(0.071)	(0.098)	(0.052)	(0.009)
Having TV	0.313	0.267*	0.255	-0.244**	-0.017
	(0.201)	(0.140)	(0.221)	(0.105)	(0.017)
Having motorbike	0.305	-0.209	0.510	-0.073	0.016
	(0.325)	(0.221)	(0.393)	(0.148)	(0.029)
Having smartphone	-0.091	-0.135	0.342**	-0.305**	0.023
	(0.205)	(0.144)	(0.168)	(0.135)	(0.016)
Distance to market	0.036	-0.052	0.070	0.017	0.002
	(0.070)	(0.046)	(0.064)	(0.038)	(0.006)
Land size	0.794***	1.048***	-0.340	0.008	-0.015
	(0.299)	(0.201)	(0.328)	(0.124)	(0.020)
Asset value per capita (ln)	0.516***	0.133	0.078	0.304***	0.013
	(0.134)	(0.102)	(0.094)	(0.076)	(0.011)
Flood	0.854	0.338	0.934	-0.287**	-0.042*
	(0.643)	(0.400)	(0.630)	(0.116)	(0.022)
Drought	-0.811***	-0.401**	-0.176	-0.165	-0.038*
	(0.312)	(0.204)	(0.358)	(0.142)	(0.021)
Khulna district	-0.833**	-0.185	-0.321	-0.516***	-0.021
	(0.340)	(0.179)	(0.726)	(0.193)	(0.027)
Satkhira district	-0.554*	0.113	-0.032	-0.757***	-0.051*
	(0.309)	(0.192)	(0.489)	(0.204)	(0.029)
Constant	0.568	2.382***	-0.804	-1.147**	0.208**
	(1.252)	(0.922)	(1.192)	(0.574)	(0.094)
Wald chi^2	116.08	104.73	63.54	48.14	22.01
p-value	0.00	0.00	0.00	0.00	0.14
Observations	720	720	720	720	720

**** p < 0.01, **p < 0.05, * p < 0.1, Robust standard errors in parentheses*

Table A17. Effects of rice-aquaculture adoption on household consumption

	(1) Total consumption	(2) Food	(3) Education	(4) Health	(5) Transport and communication	(6) Water and electricity	(7) Other non-food consumption
Rice-aquaculture	-0.356	-0.225	-0.043	-0.254*	0.098**	0.050***	0.682***
	(0.410)	(0.140)	(0.102)	(0.139)	(0.046)	(0.010)	(0.102)
Household size	-0.274***	-0.170***	0.024	-0.063	-0.014	-0.007***	-0.050***
	(0.071)	(0.041)	(0.017)	(0.040)	(0.009)	(0.003)	(0.017)
Age head	0.012**	0.006**	-0.002	0.006*	-0.001	0.000	0.002
	(0.006)	(0.003)	(0.001)	(0.003)	(0.001)	(0.000)	(0.002)
Male head	-0.128	0.139	-0.124	-0.207	-0.007	-0.014	0.066
	(0.402)	(0.154)	(0.157)	(0.268)	(0.047)	(0.017)	(0.064)
Education head	-0.002	0.005	0.034	-0.020	0.006	-0.002	0.014
	(0.072)	(0.034)	(0.027)	(0.033)	(0.012)	(0.005)	(0.020)
No. of dependent	-0.209***	-0.058*	-0.085***	-0.011	-0.041***	-0.005	-0.006
	(0.075)	(0.032)	(0.024)	(0.043)	(0.013)	(0.004)	(0.024)
Having TV	-0.115	0.063	-0.007	-0.172**	0.030	0.003	-0.055
	(0.144)	(0.081)	(0.044)	(0.085)	(0.021)	(0.009)	(0.045)
Having motorbike	0.477*	0.117	-0.110	0.241	0.275***	0.009	-0.101
	(0.245)	(0.093)	(0.069)	(0.181)	(0.042)	(0.020)	(0.069)
Having smart Phone	0.107	-0.091	0.022	0.064	0.117***	-0.007	-0.002
	(0.151)	(0.074)	(0.044)	(0.087)	(0.020)	(0.007)	(0.045)
Distance to market	-0.101**	-0.061**	-0.008	-0.026	-0.008	-0.000	0.002
	(0.045)	(0.024)	(0.017)	(0.022)	(0.007)	(0.002)	(0.015)
Land size	0.240*	0.184**	0.061	-0.082	0.044	0.018*	-0.032
	(0.144)	(0.074)	(0.039)	(0.075)	(0.029)	(0.009)	(0.060)
Asset value per capita (ln)	0.501***	0.132***	0.131***	0.121**	0.009	0.025***	0.084**
	(0.094)	(0.045)	(0.026)	(0.057)	(0.012)	(0.004)	(0.034)
Flood	0.327	-0.002	0.161	0.240	-0.028	0.024	0.013
	(0.409)	(0.143)	(0.219)	(0.162)	(0.045)	(0.026)	(0.072)
Drought	-0.192	-0.054	-0.057	-0.057	-0.027	-0.019**	0.064
	(0.199)	(0.095)	(0.050)	(0.118)	(0.031)	(0.010)	(0.067)
Khulna district	-0.726***	-0.242***	-0.049	-0.137	-0.108***	-0.034***	-0.271***
	(0.187)	(0.078)	(0.045)	(0.126)	(0.029)	(0.010)	(0.076)
Satkhira district	-0.504**	-0.145*	0.020	-0.098	-0.105***	-0.010	-0.239***
Constant	(0.200)	(0.084)	(0.052)	(0.141)	(0.026)	(0.012)	(0.084)
	0.748	1.199***	-0.489**	-0.106	0.330***	-0.062	-0.216
	(0.835)	(0.361)	(0.223)	(0.519)	(0.119)	(0.043)	(0.338)
Wald chi^2	129.74	129.74	70.10	42.14	194.84	109.17	119.47
p-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Observations	720	720	720	720	720	720	720

**** p < 0.01, **p < 0.05, * p < 0.1, Robust standard errors in parentheses*

Table A18. Farm level production diversity by rice-aquaculture adoption

	(1) Full sample	(2) Non-adopters	(3) Rice-Aquaculture adopters	(3)-(2) Difference
PDS12	3.897	3.831	4.134	0.302*
	(1.849)	(1.857)	(1.808)	
PDS9	3.873	3.805	4.121	0.316**
	(1.825)	(1.836)	(1.766)	
Number of crops species	2.313	2.378	2.083	-0.296**
	(1.476)	(1.496)	(1.382)	
Number of livestock species	1.991	2.020	1.892	-0.128
	(1.282)	(1.226)	(1.466)	
Number of aquatic species	0.712	0.512	1.433	0.922***
	(0. 756)	(0.671)	(0.591)	

**** p < 0.01, **p < 0.05, * p < 0.1; Standard deviations in parentheses*

Table A19. Effects of rice-aquaculture adoption on farm production diversity

	(1) PDS12	(2) PDS9	(3) No. of crop species	(4) No. of livestock species	(5) No. of aquatic species
Rice-aquaculture	-1.218***	-1.163***	-1.293***	-0.589*	1.887***
	(0.406)	(0.386)	(0.250)	(0.338)	(0.144)
Household size	-0.005	-0.002	0.016	0.095**	-0.019
	(0.064)	(0.064)	(0.049)	(0.042)	(0.027)
Age head	0.001	0.001	0.003	-0.001	0.001
	(0.006)	(0.006)	(0.005)	(0.004)	(0.002)
Male head	0.033	0.042	0.133	-0.394*	0.252**
	(0.347)	(0.344)	(0.250)	(0.239)	(0.108)
Education head	-0.026	-0.026	-0.007	-0.020	0.016**
	(0.020)	(0.020)	(0.016)	(0.013)	(0.008)
No. of dependent	0.074	0.065	0.084	-0.030	0.005
	(0.086)	(0.085)	(0.070)	(0.058)	(0.034)
Having TV	0.137	0.151	0.159	-0.046	-0.121**
	(0.166)	(0.163)	(0.134)	(0.105)	(0.060)
Having motorbike	0.088	0.074	0.081	-0.081	-0.055
	(0.257)	(0.253)	(0.202)	(0.165)	(0.088)
Having smartphone	0.229	0.241	-0.106	0.214**	0.072
	(0.158)	(0.155)	(0.136)	(0.104)	(0.065)
Distance to market	0.086*	0.087*	0.081*	0.070**	-0.033*
	(0.050)	(0.050)	(0.047)	(0.033)	(0.019)
Land size	0.470**	0.461**	0.147	0.047	0.121*
	(0.199)	(0.196)	(0.156)	(0.108)	(0.070)
Asset value per capita (ln)	0.232**	0.229**	0.229***	0.194***	-0.036
	(0.094)	(0.093)	(0.074)	(0.063)	(0.037)
Flood	-0.796**	-0.750**	-0.214	-0.128	0.060
	(0.362)	(0.361)	(0.280)	(0.234)	(0.142)
Drought	0.210	0.163	0.294	-0.052	0.014
	(0.327)	(0.311)	(0.252)	(0.171)	(0.081)
Khulna district	-0.618***	-0.610***	0.134	-0.317**	-0.398***
	(0.206)	(0.204)	(0.145)	(0.133)	(0.075)
Satkhira district	-0.057	-0.092	0.133	0.363***	-0.254***
	(0.217)	(0.213)	(0.168)	(0.137)	(0.076)
Constant	1.829**	1.806**	-0.213	0.297	0.576*
	(0.898)	(0.889)	(0.712)	(0.583)	(0.348)
Wald chi^2	93.24	93.29	79.47	118.51	220.01
p-value	0.00	0.00	0.00	0.00	0.00
Observations	720	720	720	720	720

**** p < 0.01, **p < 0.05, * p < 0.1, Robust standard errors in parentheses*

Table A20. Robustness checks for the effects of rice-aquaculture on HDDS

	Normal season		Lean season	
	HDDS12	HDDS9	HDDS12	HDDS9
OLS	-0.231	-0.261*	-0.420**	-0.459***
	(0.166)	(0.142)	(0.188)	(0.158)
PSM	-0.315*	-0.327**	-0.501**	-0.476***
	(0.192)	(0.164)	(0.216)	(0.179)
CFA	-0.547	-0.704	-1.693***	-1.471***
	(0.529)	(0.446)	(0.623)	(0.519)
Heteroskedasticity-based instruments	-0.426	-0.603*	-1.618***	-1.364***
	(0.414)	(0.351)	(0.503)	(0.403)

**** p < 0.01, **p < 0.05, * p < 0.1, Robust standard errors in parentheses*

Table A21. Robustness checks for the effects of rice-aquaculture on individual dietary diversity

	MDDS	WDDS	CDDS
OLS			
	-0.163	-0.210*	0.019
	(0.115)	(0.117)	(0.148)
PSM			
	-0.283	-0.321	0.042
	(0.139)	(0.138)	(0.19)
CFA	-0.102	-0.157	0.011
	(0.122)	(0.125)	(0.151)
Heteroskedasticity-based instruments			
	-0.757***	-1.037***	-0.204
	(0.244)	(0.275)	(0.312)

**** p < 0.01, **p < 0.05, * p < 0.1, Robust standard errors in parentheses*

Table A22. Robustness checks for the effects of rice-aquaculture on households with high education level

	Normal season		Lean season	
	HDDS12	HDDS9	HDDS12	HDDS9
OLS				
	-0.430	-0.116	-0.365	-0.203
	(0.289)	(0.208)	(0.245)	(0.178)
PSM	-0.309	-0.257	-0.279	-0.298
	(0.317)	(0.267)	(0.361)	(0.295)
CFA	-1.179	-1.389	-1.587	-1.268
	(1.164)	(0.986)	(1.212)	(1.028)
Heteroskedasticity-based instruments	-0.455	-0.488*	-0.226	-0.313
	(0.342)	(0.274)	(0.372)	(0.304)

**** p < 0.01, **p < 0.05, * p < 0.1, Robust standard errors in parentheses*

Table A23. Robustness checks for the effects of rice-aquaculture on households with low education levels

	Normal season		Lean season	
	HDDS12	HDDS9	HDDS12	HDDS9
OLS	-0.423	-0.443*	-0.414	-0.507**
	(0.312)	(0.244)	(0.260)	(0.204)
PSM	-0.112	-0.18	-0.388	-0.406*
	(0.239)	(0.208)	(0.27)	(0.224)
CFA	-0.204	-0.415	-1.646**	-1.434**
	(0.625)	(0.534)	(0.768)	(0.638)
Heteroskedasticity-based instruments	-0.469	-0.491	-1.264***	-1.121***
	(0.357)	(0.306)	(0.444)	(0.374)

**** p < 0.01, **p < 0.05, * p < 0.1, Robust standard errors in parentheses*

Table A24. Robustness checks for the effects of rice-aquaculture on households having older heads

	Normal season		Lean season	
	HDDS12	HDDS9	HDDS12	HDDS9
OLS	-0.554*	-0.080	-0.546**	-0.114
	(0.298)	(0.206)	(0.248)	(0.178)
PSM	-0.46	-0.44	-0.696*	-0.652**
	(0.339)	(0.282)	(0.394)	(0.316)
CFA	-0.945	-0.936	-1.793*	-1.428*
	(0.797)	(0.661)	(0.951)	(0.786)
Heteroskedasticity-based instruments	-0.518	-0.477	-0.950*	-0.828**
	(0.446)	(0.355)	(0.505)	(0.402)

**** p < 0.01, **p < 0.05, * p < 0.1, Robust standard error in parentheses*

Table A25. Robustness checks for the effects of rice-aquaculture on household having younger heads

	Normal season		Lean season	
	HDDS12	HDDS9	HDDS12	HDDS9
OLS	-0.646*	-0.361	-0.632**	-0.405**
	(0.343)	(0.231)	(0.282)	(0.195)
PSM	-0.112	-0.146	-0.271	-0.342
	(0.234)	(0.203)	(0.257)	(0.216)
CFA	-0.350	-0.571	-1.942**	-1.777**
	(0.703)	(0.614)	(0.842)	(0.714)
Heteroskedasticity-based instruments	-0.456	-0.582	-1.444***	-1.213***
	(0.452)	(0.389)	(0.541)	(0.451)

**** p < 0.01, **p < 0.05, * p < 0.1, Robust standard errors in parentheses*

Table A26. Robustness checks for the effects of rice-aquaculture on households having larger land

	Normal season		Lean season	
	HDDS12	HDDS9	HDDS12	HDDS9
OLS				
	-0.515*	-0.101	-0.511**	-0.131
	(0.288)	(0.206)	(0.240)	(0.177)
PSM				
	-0.519	-0.481*	-0.535	-0.515*
	(0.329)	(0.276)	(0.374)	(0.299)
CFA	-0.015	-0.230	-0.551	-0.630
	(0.911)	(0.735)	(1.082)	(0.856)
Heteroskedasticity-based instruments	-0.491	-0.526*	-0.262	-0.339
	(0.350)	(0.284)	(0.396)	(0.321)

**** p < 0.01, **p < 0.05, * p < 0.1, Robust standard errors in parentheses*

Table A27. Robustness checks for the effects of rice-aquaculture on households having smaller land

	Normal season		Lean season	
	HDDS12	HDDS9	HDDS12	HDDS9
OLS				
	-0.604*	-0.388*	-0.607**	-0.427**
	(0.331)	(0.232)	(0.271)	(0.196)
PSM	-0.126	-0.148	-0.338	-0.412**
	(0.239)	(0.207)	(0.265)	(0.223)
CFA	-0.668	-0.766	-2.103***	-1.752***
	(0.622)	(0.542)	(0.736)	(0.625)
Heteroskedasticity-based instruments	-0.543	-0.535*	-1.382***	-1.220***
	(0.357)	(0.305)	(0.447)	(0.375)

**** p < 0.01, **p < 0.05, * p < 0.1, Robust standard errors in parentheses*

Table A28. Robustness check for the effects of adopting rice-aquaculture on household labor allocation

	(1) Farm activities	(2) Non-farm activities	(3) Commuting	(4) Cooking & domestic activities	(5) Forest extraction activities	(6) Other activities
Panel A: Lean season						
OLS	100.912***	8.797	40.385***	-87.332***	-12.674	-33.595
	(18.374)	(19.168)	(7.012)	(17.122)	(8.391)	(39.246)
PSM	83.827***	8.673	22.923**	-67.712***	0.423	-25.192
	(23.733)	(19.994)	(8.051)	(18.11)	(5.121)	(38.415)
CFA	146.902**	-38.234	205.231***	-255.792***	-71.664***	170.248
	(66.181)	(60.215)	(23.965)	(48.894)	(22.627)	(117.189)
Heteroskedasticity-based instruments	110.396**	-33.797	109.168***	-175.440***	-29.652**	116.711
	(47.036)	(47.302)	(17.185)	(37.901)	(11.996)	(85.063)
Panel B: Normal season						
OLS	78.051***	23.885	21.526***	-66.579***	0.134	-31.673
	(18.497)	(17.197)	(7.156)	(17.149)	(4.614)	(36.140)
PSM	105.5	2.423	42.519	-88.635	-18.077	-34.00
	(23.41)	(21.062)	(8.405)	(17.692)	(8.235)	(41.52)
CFA	6.583	-5.234	142.744***	-152.661***	-0.984	227.249**
	(66.278)	(55.187)	(23.522)	(51.018)	(10.665)	(106.709)
Heteroskedasticity-based instruments	80.488*	-5.039	67.864***	-106.032***	-3.595	86.285
	(47.326)	(43.613)	(16.113)	(37.689)	(10.495)	(77.804)

** p < 0.01, **p < 0.05, * p < 0.1, Robust standard errors in parentheses*

Table A29. Robustness check for the effects of adopting rice-aquaculture on household income

	(1) Total income	(2) Farm income	(3) Off-farm income	(4) Forest extracting income	(5) Remittance, stipend and public transfer
OLS	0.424**	0.602***	0.067	-0.246***	-0.021
	(0.212)	(0.170)	(0.183)	(0.087)	(0.018)
PSM	0.458*	0.549***	0.125	-0.216**	-0.236
	(0.272)	(0.206)	(0.21)	(0.104)	722
CFA	0.542	0.520	0.890	-0.868***	-0.058
	(0.777)	(0.520)	(0.636)	(0.306)	(0.060)
Heteroskedasticity-based instruments	0.625	0.599*	0.307	-0.281	-0.028
	(0.509)	(0.355)	(0.433)	(0.233)	(0.031)

** $p < 0.01$, **$p < 0.05$, * $p < 0.1$, Robust standard errors in parentheses*

Table A30. Robustness check for the effects of adopting rice-aquaculture on household consumption

	(1) Total consumption	(2) Food	(3) Education	(4) Healthcare	(5) Transport and communication	(6) Water and electricity	(7) Other non-food consumption
OLS	-0.027	-0.094	0.082	-0.057	0.105***	0.051***	-0.054*
	(0.143)	(0.062)	(0.052)	(0.070)	(0.028)	(0.012)	(0.029)
PSM	-0.06	-0.129	0.055	-0.01	0.076**	0.041***	-0.092**
	(0.173)	(0.082)	(0.058)	(0.068)	(0.035)	(0.012)	(0.044)
CFA	-0.263	-0.174	-0.107	-0.296	0.088	0.044	0.280**
	(0.503)	(0.200)	(0.165)	(0.274)	(0.088)	(0.035)	(0.137)
Heteroskedasticity-based instruments	-0.608*	-0.411***	-0.078	-0.140	0.003	0.031*	0.070
	(0.313)	(0.139)	(0.119)	(0.150)	(0.069)	(0.018)	(0.072)

** $p < 0.01$, **$p < 0.05$, * $p < 0.1$, Robust standard errors in parentheses*

Table A31. Robustness check for assessing the effects of adopting rice-aquaculture on farm production diversity

	(1) PDS12	(2) PDS9	(3) No. of crop species	(4) No. of livestock species	(5) No. of aquatic species
OLS	0.383***	0.395***	-0.308**	-0.115	0.952***
	(0.148)	(0.144)	(0.123)	(0.115)	(0.056)
PSM	0.327*	0.342*	-0.031	-0.104	0.968***
	(0.18)	(0.177)	(0.024)	(0.14)	(0.063)
CFA	-0.880*	-0.850*	-1.646***	-0.652*	1.754***
	(0.470)	(0.458)	(0 .433)	(0 .356)	(0.175)
Heteroskedasticity-based instruments	-0.239	-0.209	-0.983***	-0.542**	1.305***
	(0.339)	(0.335)	(0.312)	(0.257)	(0.129)

** p < 0.01, **p < 0.05, * p < 0.1, Robust standard errors in parentheses*