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Agroecology

Integrated Agroecological Rice Fish Farming In Andhra Pradesh, India: A Case Study

Ayan Samaddar, Arun Padiyar Panemangalore,
Sudharsan Maliappan, Gulshan Borah, Alok Sikka,
Gopal Kumar



Authors

Ayan Samaddar ¹, Arun Padiyar Panemangalore ¹, Sudharsan Maliappan ², Gulshan Borah ², Alok Sikka ², Gopal Kumar ²

Affiliations

¹WorldFish India, New Delhi -110008, India

²International Water Management Institute, New Delhi, Delhi 110012, India

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Executive Summary

Andhra Pradesh is known as the "Rice Bowl of India" since its primary crop for commerce is rice. On the other hand, there is a current demand for alternative non-chemically dependent technology to ensure sustainability in both the economy and the environment. In order to alter the rice production system in alignment with fish and horticultural crops under an Integrated Farming System (IFS), Rythu Sadhikara Samstha (RySS) adopted the integrated rice-fish culture system as part of the Andhra Pradesh Community Managed Natural Farming (APCNF) initiative. In such a system, aquaculture is currently receiving greater attention due to its growing demand and favourable production economics requiring less effort. An initial evaluation was carried out by analyzing the physico-chemical characteristics of the water, the planktonic assemblages in water, types of inputs used, costs, results, and the pertinent farmer reactions on eight randomly selected IFS-based aquaculture system. This study demonstrated that integrating fish production in rice fields is a viable, low-risk, and ecologically friendly supplementary economic activity, offering numerous advantages, including enhanced incomes and a better supply of fish for rural agricultural communities. However, for development and extension agencies to facilitate the adoption and benefits of this model among small and marginal farmers, careful consideration of this system is imperative. It would be interesting and crucial for future research to determine the optimal fish stocking density and input distribution in terms of productivity, survival rate, and biodiversity. Ultimately, investigating how rice-fish coculture methods contribute to the aquatic environment and biodiversity may reveal new pathways to promote the agroecological transition of the system.

Introduction

The growing global population (Godfray et al. 2010), limitation of agriculture resources (such as land and water) (Kim and Arnhold, 2018) and climate change (Brown and Funk, 2008) are making rural livelihood and food security an increasingly difficult task. There are trade-offs in modern agriculture between reducing adverse effects on ecosystems and producing enough food (Tilman, 1999). Since rice is a staple food for more than half of the world's population (Bandumula 2017), an increasing number of different agrochemicals are applied in conventional rice production. It damages the ecosystem through eutrophication in lakes and oceans, pollution of groundwater, soil consolidation, biodiversity loss and environmental degradation (Abe et al. 2016; Stankus and Halwart, 2017). India ranks second in the world in terms of rice production, right behind China, with an annual production of over 130 million metric tons in 2022–2023 (Sathoria and Roy 2022; Barman 2021; Bhatt et al. 2021). The area under cultivation (currently approximately 46 million hectares) has increased by 6.22%, and the yield (currently 2809 kg/hectare) has increased by 3.19%, resulting in a 9.61% increase in rice production in India over the previous three years (Madhu et al. 2023). Although this is a positive step toward accomplishing the first two of the 17 Sustainable Development Goals (SDGs) that the UN has set for 2030—no poverty and no hunger—it has come at the expense of increased use of chemicals that pollute soil and water. Andhra Pradesh's location in the main basin of the Krishna and Godavari rivers has earned it the moniker "Rice Bowl of India", where the district of West Godavari, sometimes referred to as India's Granary, produces roughly half of the state's rice (Vijay and

Chandayya Makeni 2011). This district and many adjacent ones have seen a rise in the careless application of chemical agricultural inputs, which are increasing the likelihood of bioaccumulation and biomagnification and getting into food chains (Rao et al. 2020). These processes are thought to be detrimental to both the ecosystem and human health (Sharma and Singhvi 2017). To address these challenges, the Andhra Pradesh government launched "Andhra Pradesh Zero Budget Natural Farming (AP-ZBNF)" in 2016, which was later renamed to "Andhra Pradesh Community Managed Natural Farming (APCNF)" in 2020, to emphasize farmers ownership. AP-ZBNF and APCNF programs were built on an earlier programme called 'A.P. Community Managed Sustainable Agriculture', which was managed by state governments rural development department from 2004 to 2014 (<https://apcnf.in/ryss/>). APCNF program is run by the non-profit government organization for farmers' empowerment, "Rythu Sadhikara Samstha (RySS)," under the direction of the AP government's Department of Agriculture.

Southeast Asian nations heavily utilize the integrated rice-fish culture system, which is a globally significant agricultural heritage system (Ahmed and Garnett, 2011; Bène et al., 2016). The integrated rice-fish culture system has the potential to decrease expenses, boost economic benefits, and improve the quality of both fish and rice when compared to the traditional rice monoculture system (RM) (Wan et al., 2019). The combination of rice and fish increased farmers' profits because it produced additional revenue from fish in addition to rice, which increased the amount of animal protein available for human consumption. With its focus on enhancing farmer net incomes, soil health, biodiversity, dietary diversity and climate change resilience, the Integrated Rice -Fish Farming System (IRFS) was found suitable to expand the agroecological movement in Andhra Pradesh by addressing APCNF's objectives, i.e. improving farmer net incomes, soil health, biodiversity, and resilience to climate change. Furthermore, APCNF's implementation of IRFS may increase the availability of fish and other aquatic animals which will help in achieving food and nutritional security of the local population. In addition to improving soil health and reducing greenhouse gas (GHG) emissions, IRFS can alter and increase the activity of the microorganisms overall and their ability to recycle nutrients (Bashir et al. 2020). It is remarkable that the entire zone of Godavari delta region of Andhra Pradesh is suitable for IRFS, considering the diverse topography and climate conditions which is essential to make IRFS work.

The viability of combining fish culture and rice cultivation has been drawing more attention recently because of the significance of rice and fish to the national economy, the depletion of wild fish stocks, and the rising demand for fish protein (Sathoria and Roy 2022). This could lead to a significant increase in the number of rural households having access to fish. Whereas, the primary elements of paddy ecosystems are rice, water, phytoplankton, zooplankton, and zoobenthos, these elements may interact. For instance, rice and phytoplankton may lower the levels of phosphorus and nitrogen in the water, regulating its quality. Zoobenthos may mediate the flow of energy throughout the ecosystem (Li et al. 2021). However, microorganisms are also necessary for the formation of soil structure, the decomposition of organic matter in the soil, the flow of nutrients through the soil, and the growth and health of crops. Furthermore, fish naturally consume phytoplankton and zooplankton, and their relationship changes the water's quality and the food chain (Elser and Goldman, 1991; Ersoy et al., 2019). To fully understand the ecological legacy of introducing fish into rice fields and its justification, a thorough investigation is

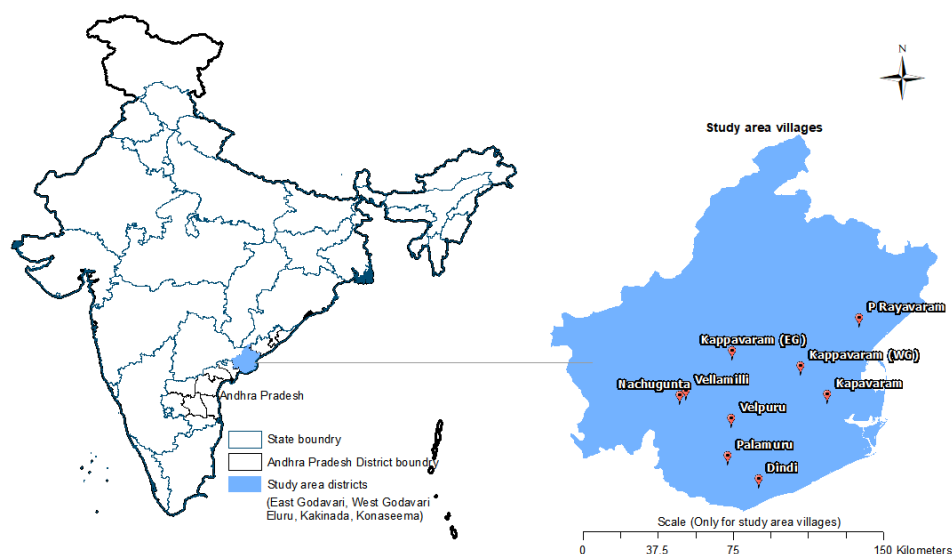
required. Therefore, soil and water environments, their potential roles in the farming system, and current IRFS-based farming practices will all need to be documented in order to inform an agroecological transition pathway to more sustainable IRFS in Andhra Pradesh.

When compared to conventional chemical-dependent rice production, natural farming-based rice production is somewhat more productive and profitable (Kumar et al. 2023); however, sustainable agroecology-friendly fish production strategies in paddy fields still need to be evaluated. Therefore, the purpose of this study is to assess the environmental effects and technical-economic viability of implementing IRFS in some of the potential district of Andhra Pradesh while adhering to APCNF's natural farming rules. The feasibility assessment has considered the cost of cultivation, the availability and dependence on resources, and the environmental conditions related to aquaculture along with a hypothesis that can influence the adoption behaviour of this practice in the community. The purpose of this research is to comprehend the system as a whole and evaluate its applicability for fish production in rice paddies while maintaining the coherence of agroecological principles.

2. Materials and Methods

2.1 Study area

Andhra Pradesh state of India possess six distinct agroclimatic zones, among which the present study has been conducted in 5 districts of the Godavari delta region. Based on the information provided by the Department of Agriculture, Government of Andhra Pradesh, and RySS, eight randomly selected IFS have been assessed out of the total of twenty well-performed IRFS of APCNF; which was the subject of the initial survey. The principal criterion in this selection process was the historical duration of each farming practice. The farming methods were given second priority. There were differences between management practices regarding the use of external inputs, mainly the amount and quality of type of fish seed, supplemental feed and the frequency of applying biofertilizers for fish production. The study location details have been depicted in Figure 1 (Location Map).



Special focus has been directed towards West Godavari, considered as the Agroecological Living Landscape (ALL) within the framework of CGIAR Agroecology Initiative. The average annual rainfall of West Godavari is 1055 mm, in which 79% (835 mm)

of the rainfall is received during southwest monsoon (Jun-Sep), and 29% (307 mm) is received during northeast monsoon (Oct-Dec) (APSAC, 2021). Paddy is the main crop and farmers also practice Rabi and Kharif cultivation. From 1998 to 2020, average yearly paddy sown area is 801589 ha with average yearly production of 2864343 MT. Average kharif sown area (1998 to 2020) is 467501 ha producing 1313146 MT, whereas rabi sown area for the same time period is 334089 ha producing 1743325 MT. Rabi production is higher than the kharif production, even though area sown during rabi season is significantly lesser than kharif season. Average yearly yield is 3.58 MT/ha, but the yearly yield has increased significantly (4.23 MT/ha) for the last five years (2016 to 2020). Average yearly yield for kharif season is 2.81 MT/ha and for rabi season is 4.64 MT/ha. During 2015 to 2020, it produced higher yield than previous years, kharif season 3.39 MT/ha and for rabi season 5.22 MT/ha. The 5 study districts play a crucial role in attaining food security and hold the potential for improvement through the introduction of rice-fish system leading to economic and nutritional diversification.

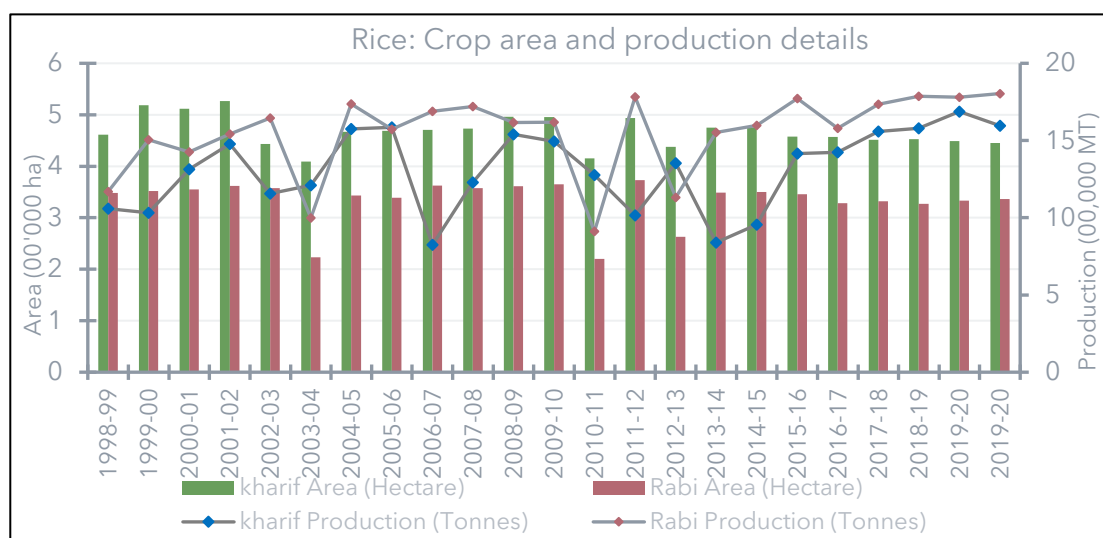


Figure 1: Rice - Crop Sown area and production of 5 districts.

Source: Authors analysis using data from DACNET portal (<https://aps.dac.gov.in/APY/Index.html>)

Furthermore, West Godavari held the highest ranking in both freshwater aquaculture and commercial fish production. The study area is primarily made up of medium-sized and smaller irrigation canals that can naturally supply enough water to the paddy fields. These canals are frequently used in conjunction with small mechanical pumps and boring rigs to provide life-saving irrigation, primarily during Rabi. Under continuous irrigation support from the Godavari River, the rice fields of West Godavari are an ideal place to promote fish culture in rice fields. APCNF has created a special "Integrated Farm Structure" (IFS) with a total area of one to two acres to encourage natural farming. The mid (50% of the field area) portion of the field is used for rice cultivation, about 20% of the peripheral converted into trench remains filled with freshwater and outer 30% area is converted to high dike used for horticulture. Eight distinct IFS located in 5 districts were used for the current study (Table 1).

Table 1: Specifics about the study's location

Site	Date of survey	Name of the Farmer	Village name	Mandal name	District name	Total area of IFS (Acre)	Effective water area for pisciculture / Trench area (Acre)
S1	26 Sep 2023	Nagireddy Omkar	Kapavaram	Kovvuru	East Godavari	1	0.2
S2	26 Sep 2023	Parimi Rajendra Prasad	Vellamilli	Unguturu	Eluru	1	0.2
S3	26 Sep 2023	Gadde Venkataratnam(Ratnaji)	Nachugunta	Unguturu		1.5	0.4
S4	25 Sep 2023	Penumarthi. Papa Rao	Velpuru	Tanuku	West Godavari	1.5	0.45
S5	25 Sep 2023	Kalididi Rangaraju	Palamuru	Veeravasam		1.5	0.4
S6	25 Sep 2023	Guttula Subbarayudu	Kapavaram			1.1	0.3
S7	27 Sep 2023	K Krishna	P. Rayavaram	Gollaprolu	Kakinada	1.5	0.3
S8	28 Sep 2023	Kolla Bathula Mohan Rao	Dindi	Amalapuram	Konaseema	1	0.2

2.2 Demography of study area

Agro-climatic zone of the study area districts is classified as Krishna Godavari Zone (AP-1) (as per NARP) and east coast plain and hill region (XI) (as per planning commission). Agro Ecological zone of the study area district is classified as Eastern Coastal plain, hot sub-humid to semi-arid eco region (as per ICAR). Major soil types found in the study area are alluvial, sandy alluvial, deltaic alluvial, coastal sandy loams, heavy clays, saline, clay loam, red sandy loam and sandy clay loams. Net sown area of West Godavari and East Godavari are 0.432 Mha and 0.418 Mha respectively. Gross cropped area (net sown area + area sown more than once) are 0.7 Mha for West Godavari and 0.766 Mha for East Godavari. Both the districts are primarily dominated by irrigated agriculture. The cropping intensity of West Godavari and East Godavari are 162% and 183% respectively. In West Godavari, net irrigated area, gross irrigated area and rainfed area are 0.365 Mha, 0.613 Mha and 0.068 Mha respectively. In East Godavari, net irrigated area, gross irrigated area and rainfed area are 0.278 Mha, 0.490 Mha and 0.140 Mha respectively. The major sources of irrigation are canals, tanks, open/bore wells and other minor water resources. In West Godavari, canals supply water to 50%

of the total irrigated area and 41.5% from open/bore wells (NICRA-ICAR, 2011a).. In East Godavari, canals supply water to 61.6% of the total irrigated area, 22% from open/bore wells and 12.3% from tanks (NICRA-ICAR, 2011b). The study areas are home to commercial rice farmers, who mainly rely on farming for their livelihood and nutritional security. They are mostly literate and rely on both internal labor and labor hired from outside sources. The majority of them are renowned for having an innate ability to cultivate rice and irrigate effectively. However, aquaculture is a lucrative business to all of them, as Andhra Pradesh serves as the most promising and most productive zone of India in terms of aquatic food production, having well organised market linkage facilities. In addition, with a significant local demand, fish ranks as the second most important non-vegetarian food item, after broiler chicken. Many rice farmers were unable to adopt commercial aquaculture due to a lack of funding and technical expertise, but this same lack of resources also acted as a catalyst for the use of IRFS-based trench areas to achieve acceptable fish productivity. West Godavari district has a 23-kilometer coastline and a continental shelf area of 536 square kilometres. The Godavari River spans 120 km with west Godavari. There are 26 fishing villages with a population of 2,98,398. West Godavari district ranks first in overall fish and prawn output and has generated 11,28,420 Mts. Represents approximately 24% of the state's production in 2020-21, with a GVA of 12450 crores (NABARD, 2023a). East Godavari district is particularly significant in Andhra Pradesh's fisheries map. The area is endowed with abundant marine, inland, and brackish water resources. In 2019-20, East Godavari District recorded 4.01 lakh MT of aqua output, ranking fourth in the state (NABARD, 2023b).

2.3 Adopted Cultivation Procedures

2.3.1 Rice cultivation procedures

Raising Pre-Monsoon Dry Sowing (PMDS) with eighteen crop varieties have been done before Kharif; seeds were sown in May and left until the second week of July (about seventy-five days) in order to achieve good biomass and crop stand. Pre-monsoon dry sowing, or PMDS, supported farmers to collect a percentage of various crops, vegetables, and leafy vegetables for their own food. Additionally, some biomass have been utilized as mulch, as fodder, even for soil nutritional enrichment before kharif planting. In irrigated paddy fields, direct planting (Line) has been maintained to achieve least amount of soil disturbance. During the land preparation process, Ghanajeevamrutham (GJM) and Dravajeevamrutham (DJM) applied as the key biofertilizers at the foliar and soil levels in compliance with prescribed dosages. Application of Azolla has also been adopted. There has been detail discussion on land and input preparation methods and techniques elsewhere ([apcnf-gujarat.pdf \(manage.gov.in\)](#)). *Azolla* sp. has been cultivated in paddy fields, where it serves as a nitrogen fixer and weed reducer. It also serves as live organic mulch, reduced the need for frequent irrigation by reducing water loss through evaporation. The application of natural pest management techniques, such as removing leaf tips, cleaning out alleys, enclosing, bundling, and encircling plantations, in addition to manual methods like putting up light traps, bird perches, yellow sticky traps, and pheromone traps for yellow stem borer have been adopted. While various plant-based extracts are also prepared, fermented, and



employed as natural insecticides, specifics are given in ([apcnf-gujarat.pdf \(manage.gov.in\)](#)). Egg Amino Acid, Panchagavya, and Saphadhanyakura tonic also applied as yields booster both in terms of quality and quantity ([apcnf-gujarat.pdf \(manage.gov.in\)](#)). Harvesting normally normally completed by October. Dry sowings of rabi start in November, specifics of other sources' methods ([apcnf-gujarat.pdf \(manage.gov.in\)](#)).

In order to get a strong crop, stand and biomass after kharif, Rabi Dry Sowing (RDS) also been adopted with at least nine varieties of crops (which include pulses, oil seeds, millets, vegetables, and leafy vegetables). RDS planted as a relay crop in the second week of November and generally continued until the second week of December (around 30 days). After that, the previously mentioned techniques were used to cultivate paddy during the rabi season, albeit there were some small and significant qualitative variations in the preparation and application of the field, details are accessible elsewhere ([apcnf-gujarat.pdf \(manage.gov.in\)](#) the survey).

2.3.2 Fish cultivation procedures

Every Integrated Farming System's (IFS) trench area was used for fish farming for a minimum of six months and a maximum of ten months. Most of the IFS's trenches were dry throughout the pre-monsoon season, lime followed by GJM were applied right before the monsoon began. Advanced fingerlings and yearlings of fish purchased locally were placed into the trench region in July and August. Many farmers continue to use supplemental feeding on occasion, but the majority exclusively rely on natural processes, with DJM being applied frequently as the principal fertilizer. A method of harvesting, either partial or complete, has been used. The aquaculture portion of rice-fish farming is still unregulated and unrecorded, depending largely on the experience and knowledge of the farmers.



A glimpse of the community-managed natural farming practices in Andhra Pradesh. Photo credit: Ayan Samaddar, WorldFish India

2.4 Design of the study

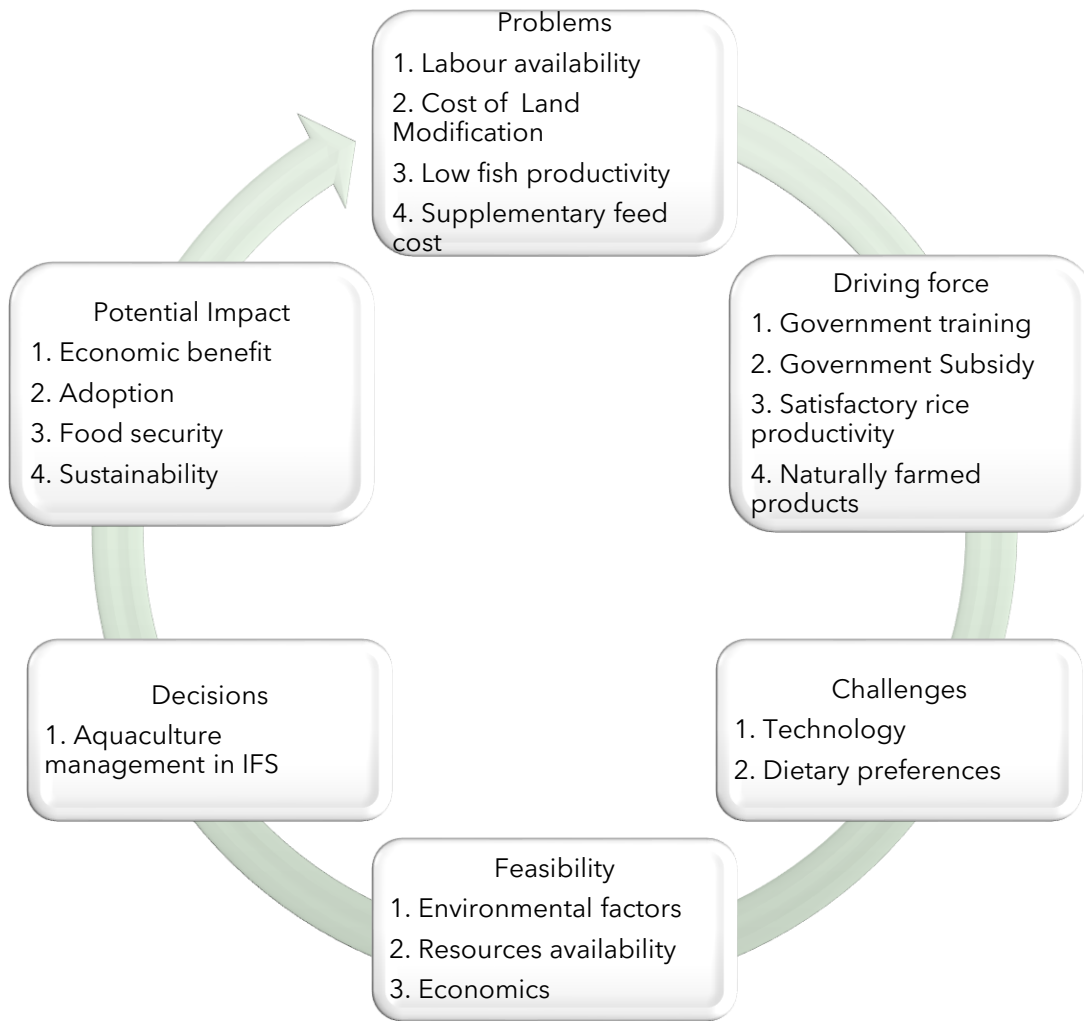


Figure3: Design of the study

The study design is shown in Figure 3, along with the problem selection, forces driving the problem, challenges, and critical elements for feasibility analysis, all of which may aid in making decisions that will have a significant influence. In collaboration with the Department of Agriculture, Government of Andhra Pradesh, and RySS, our research partner, we set out to investigate the aquaculture portion of this particular land type. Outstanding work has been done by our partners to optimize and enhance the natural farming-based agriculture and horticultural system among the surveyed Integrated Farming Systems (IFSs); however, the aquaculture component is still poorly understood. Therefore, we aimed to comprehend the socioeconomic and environmental factors in order to propose an optimal and sustainable aquaculture in paddy field-based ecosystem. Attempt was made to comprehend the effects of inputs used in the cultivation of rice and fish in IFS and their impact on aquaculture environment in all selected IFSs, as well as how they affect the quality of the water. Horticulture has been excluded because it has less direct influence over the other two components of IFS. Both qualitative and quantitative input and output have been investigated and compared to comprehend the economic viability of IFS based aquaculture. In addition, this survey was created to gauge social reactions from relevant parties.

2.5 Methodologies

2.5.1 Survey based information gathering

An organized and thoroughly tested questionnaire was used to gather the primary data. In the village clusters, case studies and focus groups were also held. The information gathered from these methods was utilized to validate the data obtained from the survey and to triangulate the information. Targeted farmers' specific farm-level data was gathered through in-person interviews utilizing a comprehensive interview schedule that had been pretested. Additional required Information obtained from villages, mandals, district and state level APCNF representatives.

2.5.2 Water sampling

Three distinct farms have provided water samples, with each farm providing water from five distinct zones within each IRFS. Water was collected in September 2023 by 6:00-7:00 hours using the techniques described by Gogoi et al. (2022). A digital multiprobe (Hanna Instruments - HI9811) was used in the field to measure the temperature, pH, EC, and TDS of the water. Secchi disc was used to measure the transparency of the water (Strickland & Parsons, 1972). Using titrimetric methods-based test kits from Hanna Instruments (SKU: HI3810, SKU: HI3810, SKU: HI3833, SKU: HI3874, SKU: HI3873 & SKU: HI3824), dissolved oxygen (DO), carbon dioxide (CO₂), phosphate (PO₄³⁻), nitrate (NO₃⁻), nitrite (NO₂⁻), and ammonia (NH₃) were measured in the field. The measurements were made using the standard methods described in APHA (2012).

Plankton analyses were performed to the genus level, and some zooplankton analyses were conducted to the species level, using techniques that were somewhat modified from those reported by Chattopadhyay et al. (2019). 50 ml planktonic samples were obtained by passing 50 liters of subsurface water through a plankton net (20 µm silk bolting mesh) after it was collected from three different locations (10 L/Location; one from the middle and four from different corners) using graduated plastic containers. The samples were then promptly preserved in 4% buffered formalin. Plankton samples were taken early in the morning (6:00-7:00 hrs.) during the study period. Using a Nikon Eclipse-Ci microscope with a 40-60X magnification, the phytoplankton population was identified down to the genus level (Akter et al., 2015); In contrast, a similar microscope was used to identify zooplanktons using a 10-20X magnification, adhering to the methods outlined by Pocięcha and Amirowicz (2003). Using a Sedgewick Rafter Cell-Counter, 1 mL of the subsample was taken for the quantitative analysis. Four randomly chosen squared cells were counted per sample, and for zooplanktons, 1,000 fields of 1 mm³ of S-R (Sedgewick-Rafter) cells were used. The formula below was used to determine the amounts of phytoplankton (measured in units L⁻¹) and zooplankton (measured in nos. L⁻¹).

- Phytoplankton abundance = $(\text{Number} \times 1000 / \text{Volume of grid (0.1 mm}^3) \times (\text{Concentrated volume} / \text{Sub volume}) / (\text{Total Volume} \times \text{Number of squares counted})$
- Zooplankton abundance = $\text{Number} \times (\text{Concentrated volume} / \text{sub volume}) / \text{Total volume.}$

2.5.3 Data analysis

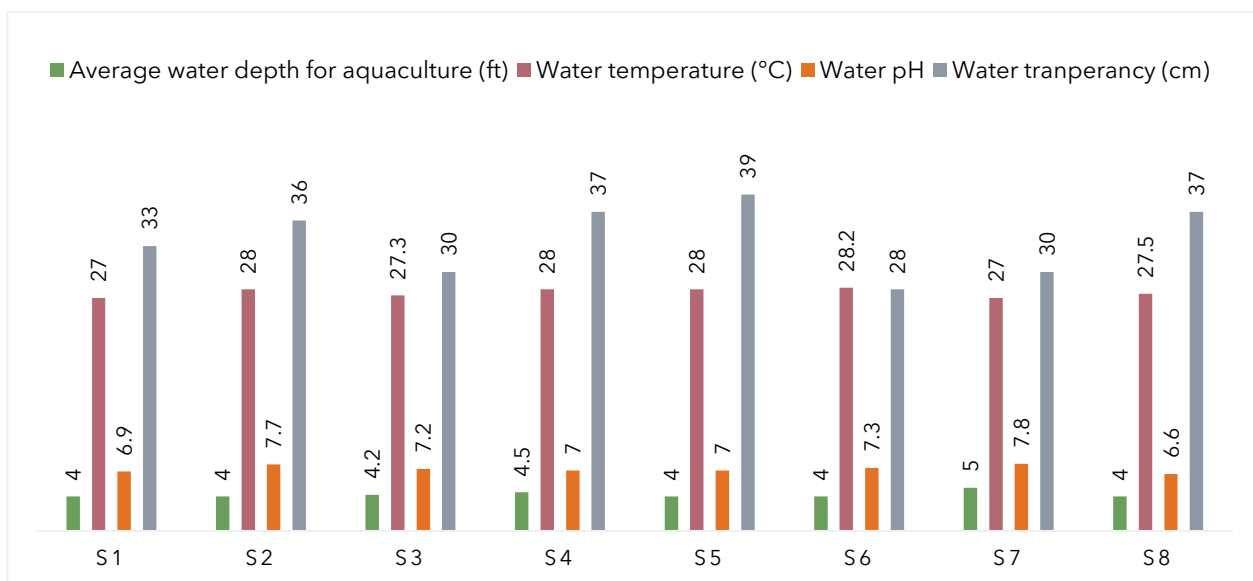
Single factor analysis of variance followed by least significant difference test (Gomez and Gomez 1984) were employed to test significant difference in Water, pH, EC, TDS and Temperature, DO, CO₂, PO₄³⁻, NO₃⁻, NO₂⁻, NH₃ and different types of

phytoplankton and zooplanktons assemblage patterns of the eight different IRFS systems. Significant differences in physico-chemical properties of water and plankton assemblage patter between each site determined.

3. Results

Physicochemical parameters of water

Figure 4 shows the changes in the physicochemical characteristics of water in response to the naturally occurring farming-based IFS system. There was significant variation observed among water temperature and transparency level. Wide fluctuations observed in water pH level which ranges from 6.6 (S8) to 7.8 (S7). Significantly higher dissolved oxygen levels are shown by S1, S2, S3, S4, S5, and S6, but S7 and S8 continue to have lower levels. S2, S5, S7, and S8 show noticeably higher levels of carbon dioxide, whereas S3 and S4 show the lowest levels ever measured. While the range is similar at the other sites, the water salinity in S5, 6, and 7 is significantly higher. The concentration of orthophosphate was found to be significantly low in S8 and significantly high in S2. A significant elevated nitrate value was observed in S4, which was followed by insignificant variations in S6, S7, S8, and the remaining sites, while the nitrite value was significantly high only in S5. Significantly lower ammonia concentrations were found in S4 and S8, whereas S5 and S7 had higher concentrations.



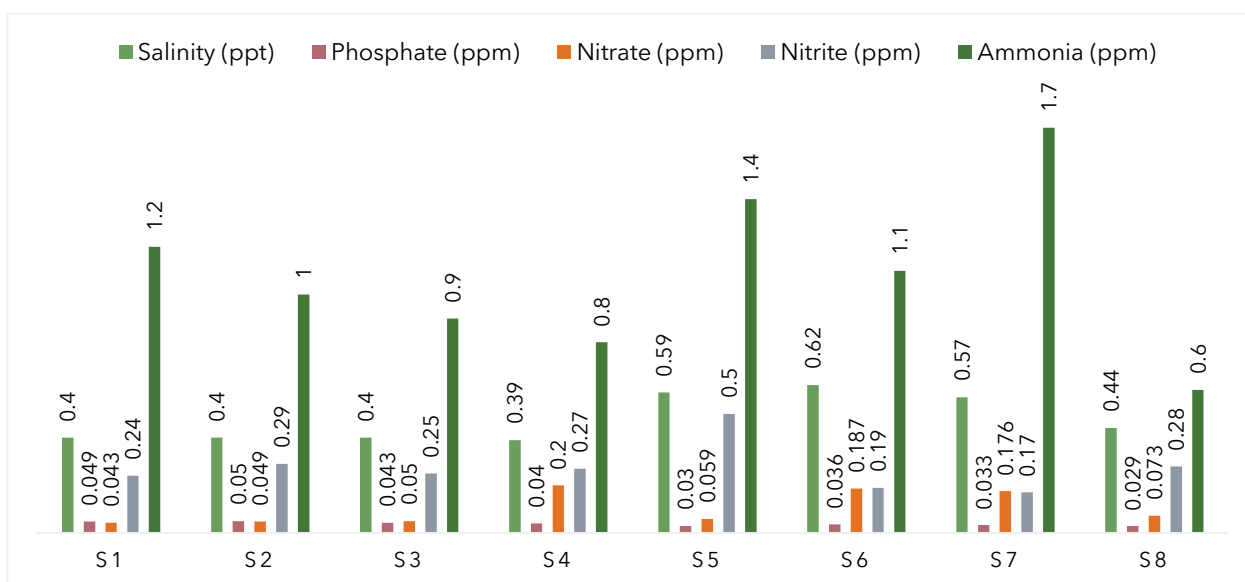
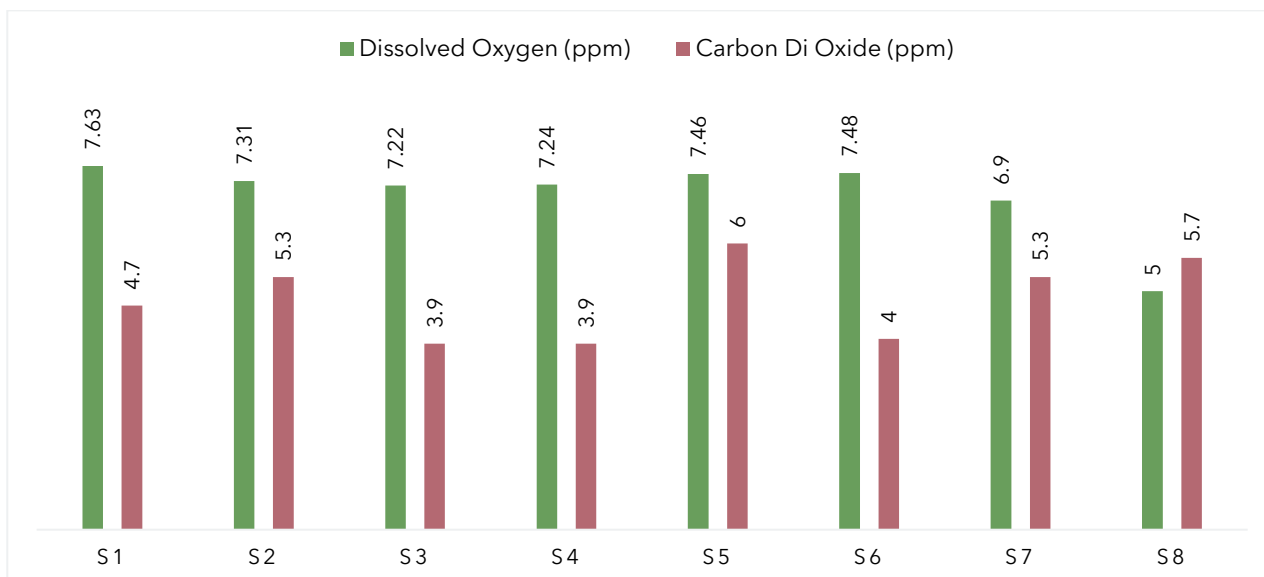


Figure 4: Water's physicochemical characteristics in various IFSs

Planktonic assemblages in water

There are ten distinct classes of phytoplankton that have been identified. With the exception of S6, where Euglenoida dominated, all samples had a significantly higher biomass and abundance of phytoplankton than S7, where Chlorophyceae was the dominant class. The population of Cyanophyceae in S7 was notably higher than in other Sites. The population of Bacillariophyceae S2 was significantly higher than that of other classes, securing its place as the second dominant class. Only the low range populations of Dinophyceae were found in S5 and S6. Trebouxiophyceae were also present at all sites in low range. With the exception of S5 and S6, very little Ulvophyceae was discovered. The only extant chonoflagellate are in S7 and S8. Magnoliopsida is restricted to S4. Coscinodiscophyceae's minimum range is limited to S5 and S6. Assemblage pattern have

been depicted in the figures shown in Figure 5.

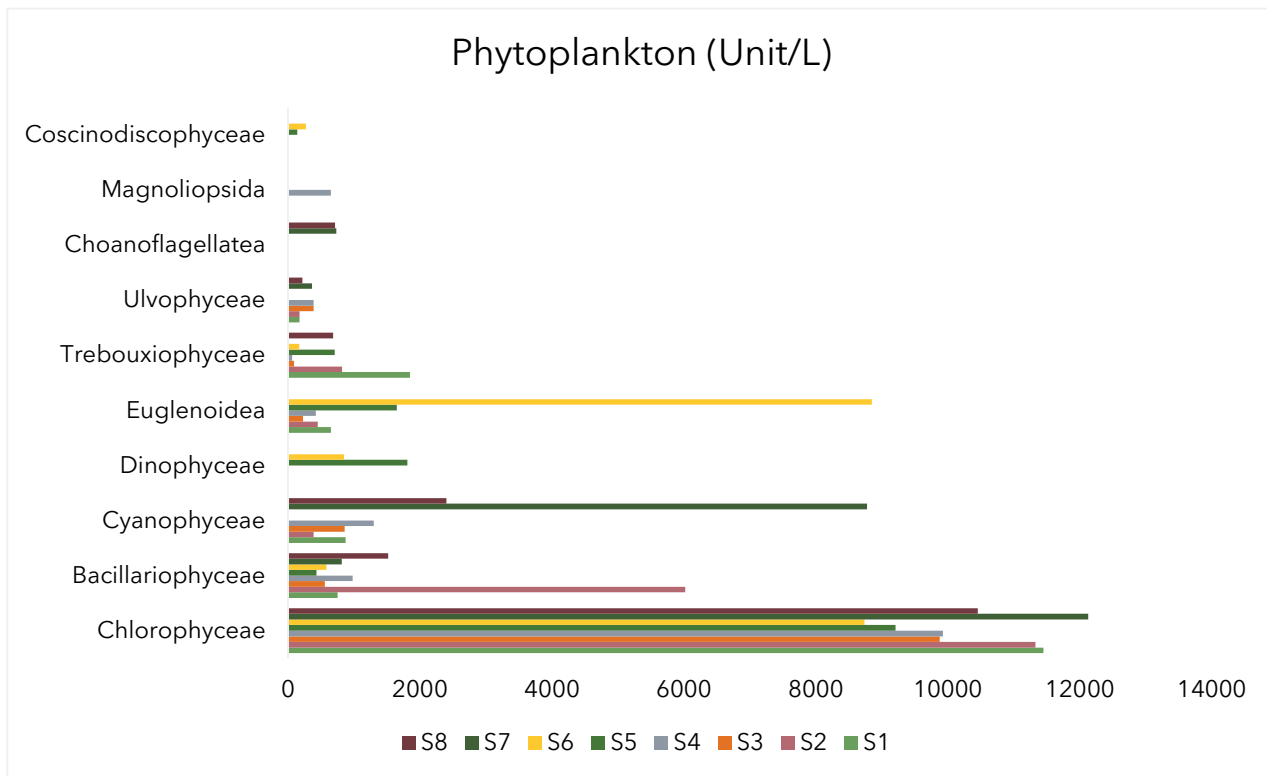


Figure 5: Patterns of phytoplankton assembly in several IFSs

It has been determined that zooplankton belongs to six different classes, which are members of. The densest populations of

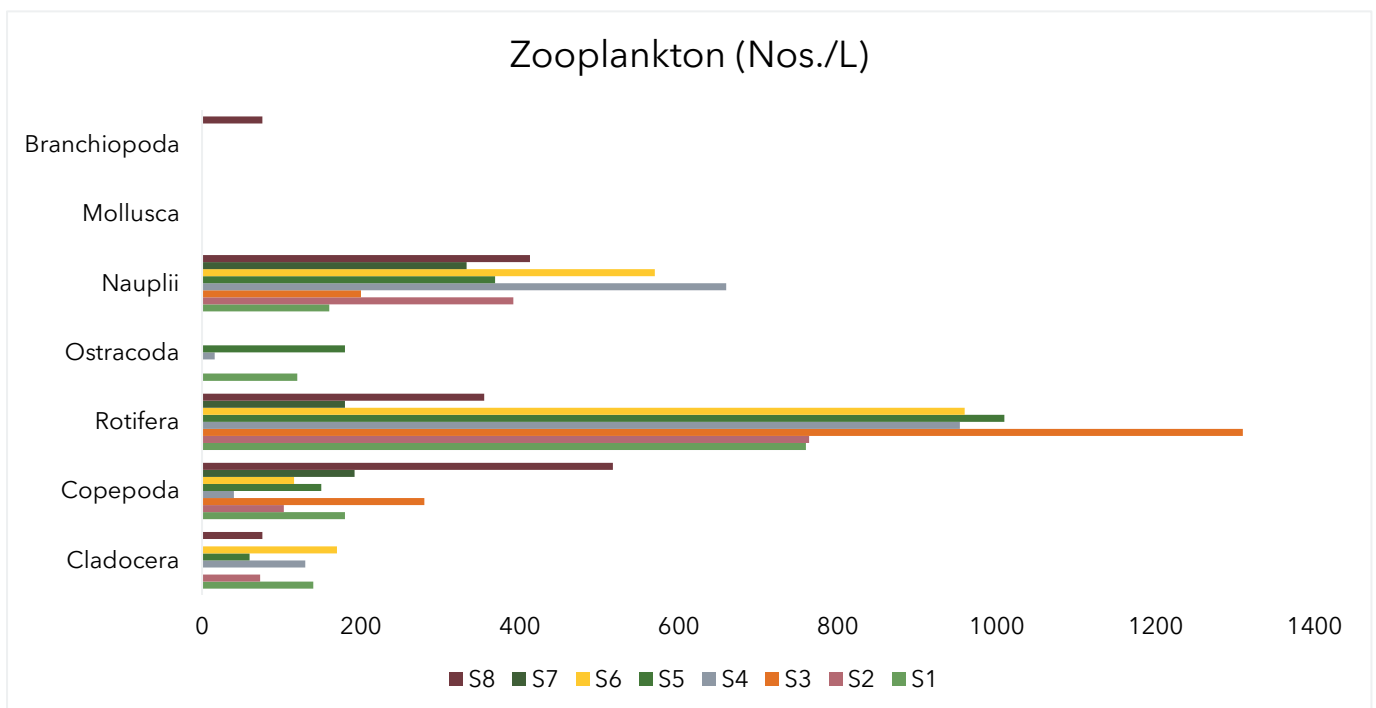


Figure 6: Patterns of zooplankton assembly in several IFSs

rotifera and zooplanktons have been found among S3. After that, S4, 5, and 6 exhibit a moderate zooplankton population density, with rotifera populations predominating. Copepoda and Nauplius, the two dominant zooplanktonic groups in S8, have notably high populations. With the exception of S3, the density of nauplius populations was significantly higher in other groups, while S4 dominated others. In certain instances, certain zooplankton groups were completely absent, or available in much smaller ranges. The plankton assemblage pattern displayed in Figure 6.



Major predatory planktons in Andhra Pradesh’s rice fish system: Photo credit: Ayan Samaddar, WorldFish India

Productivity and economics

Within the trench areas of the respective IFSs, the average depth of water varies from 4 to 5 feet, and it is available for 8 to 10 months. The most common fish varieties are Indian Major Carps (IMC) (*Catla catla*, *Labeo rohita*, and *Cirrhinus mrigala*). An innovative combination with IMCs was attempted by an S3 farmer, who used the dominant Rupchanda fish (*Pampus chinensis*). Although farmers of S5 and S6 also used advanced fingerlings, advanced fingerlings were primarily used as the stocking variety. Small native non-targeted fish species were also present in each IFS’s natural habitat alongside the target fish varieties (Table 2).

Table 2: Important features of the aquaculture system based on IFS

Site No.	Average water depth for aquaculture	Water retention month for aquaculture	Cultivated fish species	Natural abundances of predatory aquatic animals in the IRFS	Type of fish seed used	Types of fertilizers used	Types of Fish Feed Used	Abundance of natural fish species
S1	4	8	Carps	No	Advanced fingerling	GJM & DJM	No	Yes
S2	4	8	Carps	No	Advanced fingerling	GJM & DJM	No	Yes

S3	4.2	10	Carps & Rupchanda	Yes	Advanced fingerling	GJM & DJM	Commercial feed	Yes
S4	4.5	10	Carps	No	Advanced fingerling	GJM & DJM	Rice bran	Yes
S5	4	8	Carps	No	Yearling	GJM & DJM	Commercial feed	Yes
S6	4	8	Carps	No	Yearling	GJM & DJM	Rice bran	Yes
S7	5	10	Carps	No	Advanced fingerling	GJM & DJM	Commercial feed	Yes
S8	4	8	Carps	No	Advanced fingerling	No	No	Yes

Fish stocking is typically done in August and September; of the eight sites, only S2 had unusually high densities. There were negligible variations in the liming rate, but none at all in S8. While supplemental feeding was used in every instance on occasion, the rate in S3 and S5 was noticeably greater than in the other groups. Fish productivity is also comparatively higher in S3 and S5, while S4 and S8 record the lowest performance (Figure 7).

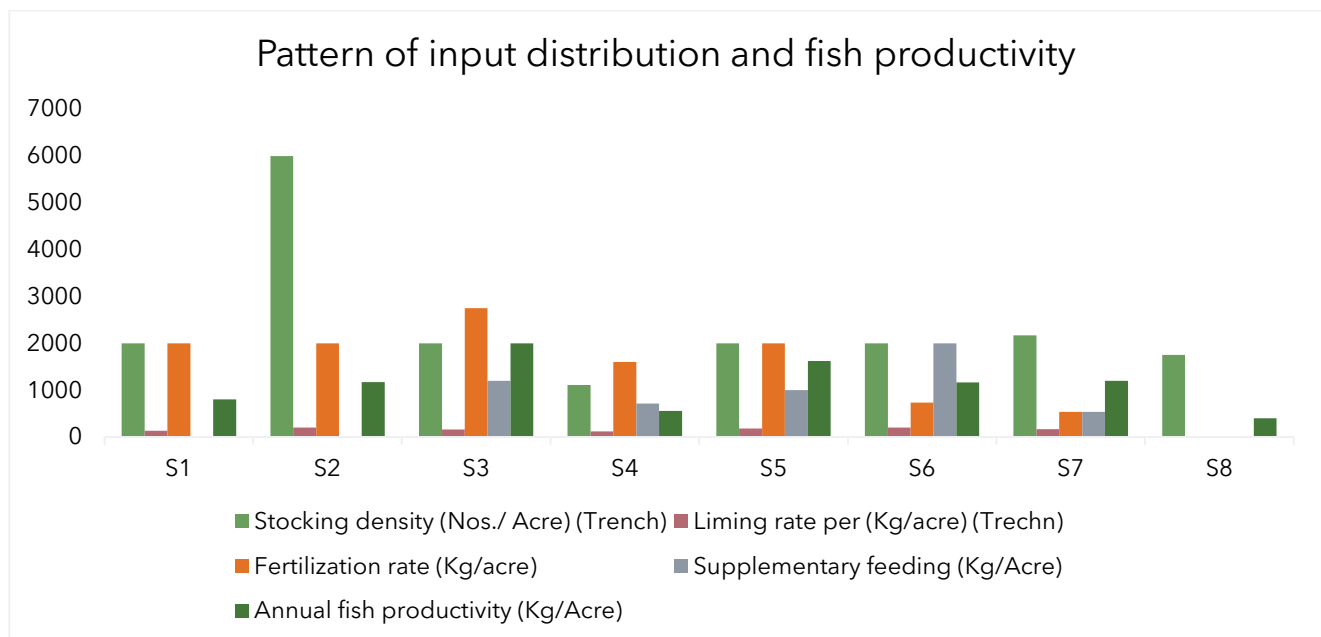


Figure 7: Key components of the IFS-based aquaculture system

Fish stocking was the most expensive area of all the IFS's aquaculture process, and supplemental feeding continues to be the second-most important area of expenditure, whichever approach is chosen. S5 incurred significantly more costs due to their large yearling stock, whereas S8 incurred the lowest. There was a correlation between gross expenditure and output across all sites when it came to the market value of the fish produced. In S3, profitability was noticeably higher than in S4 and S8. Similar

production values are shown by S2, S6, and S7, however the latter's profitability was higher. S5 had the highest gross expenditure, but in S3 productivity was higher (Figure 8).

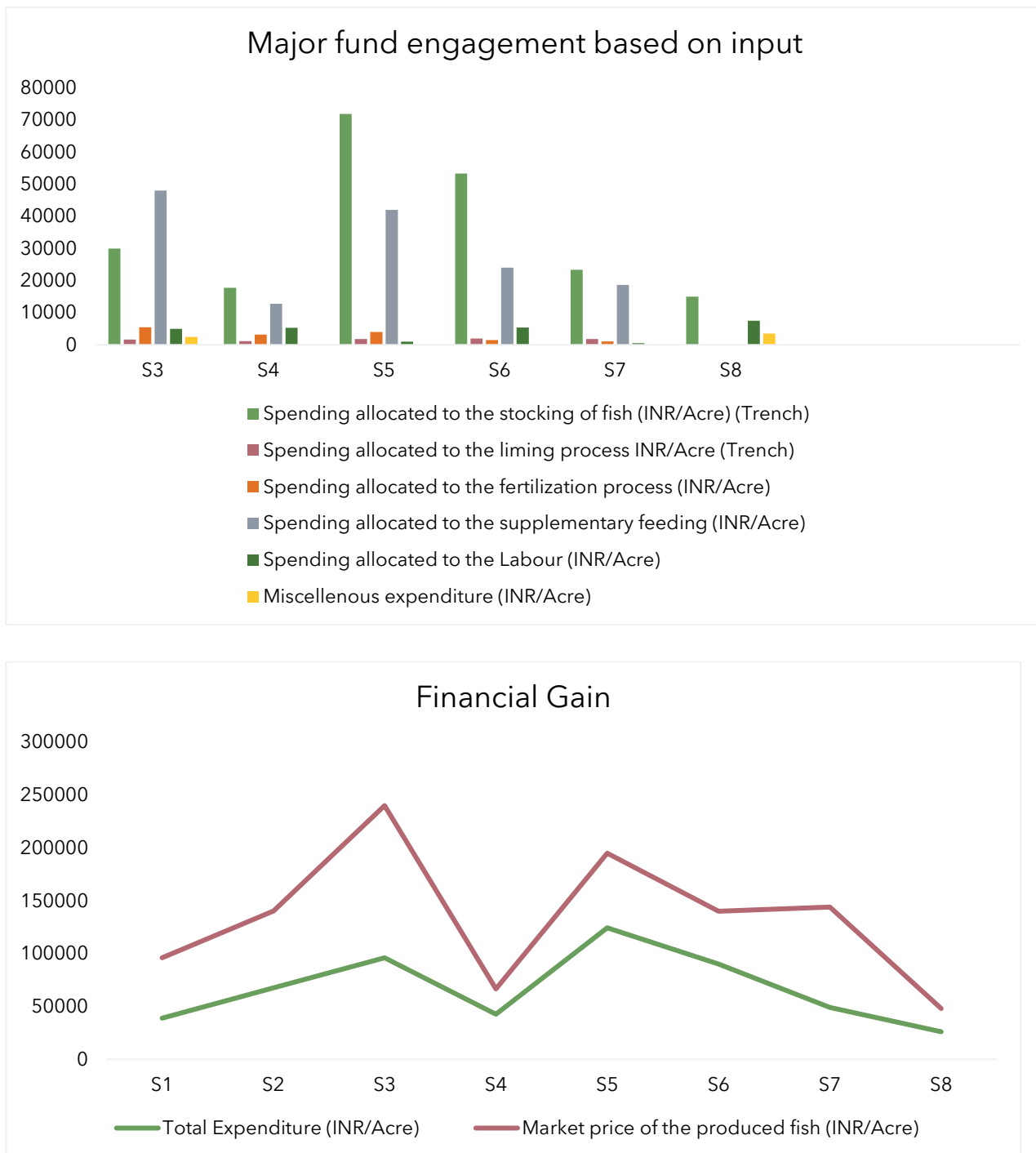


Figure 8: Important financial inputs and outputs in an aquaculture system based on IFS

Social reactions regarding IFS based aquaculture

This study provides a framework for examining aquaculture's linkages to rice and nutritional security by elucidating key hypotheses concerning the role of aquaculture in IRFS and income systems in APCNF's selected districts. Taking examples from

developing Asia, where aquaculture showed a steady growth over the last decade, the implications of aquaculture development are examined from the standpoint of its impact on employment, income and consumption.

“Analysis revealed clear evidence of positive income and consumption effects of aquaculture on households”



Satisfactory fish growth performance in a West Godavari based rice fish farming system: Photo credit: Rashmi Ranjan Das, WorldFish India

We noticed that all the IFS farmers were interested in raising carps and other native finfish and shellfish varieties, which have significant local value. They wish to increase the IFS-based intervention on a commercial basis because they are worried about the profitability of fish farming. Despite this, S2 and S4 farmers are dissatisfied with fish productivity. By incorporating some exotic, highly productive varieties like Rupchanda, S3 farmers are now demonstrating a greater interest in fishing. Fish was a welcome addition to the diets of paddy farmers. They are now very interested in learning how to increase productivity while

lowering input costs. However, the primary issues with IFS-based aquaculture are still the high investment for building an IFS and secondarily fish feed and seed cost. The positive and significant relationship between extent of adoption of recommended practices with size of operational land holding, mass media exposure and availability of fishpond ensures the possibility of manipulating these crucial factors in order to bring about desirable changes in the adoption behaviour of farmers in the study areas.

4. Discussion

September 2023 marked the beginning of the fish cultivation phase in APCNF's IFSs. During this time, each IFS received water and underwent one to two months of preparatory procedures, which helped to clarify the ecological mechanisms of the rice-fish coculture system. Average depth of water and temperature of respective IFS system been considered as normal for composite carp culture and for monitoring of important physicochemical parameters. In most of the cases water pH value shows acceptable range and in fact in some sites where it was in between 7.5 to 8.0 considered to be most ideal for composite carp culture (Heydarnejad 2012). Though in some cases reduced pH level indicated either mismanagement of liming or excess decomposition of organic products (Walse et al. 1998). As a significant abiotic component of paddy field ecosystems, dissolved oxygen (DO) may have a direct or indirect impact on soil nitrogen conversion and rice nitrogen absorption (Mishra and Salokhe, 2010). It has been shown that while lower oxygen levels can lower ammonia absorption, dissolved oxygen can boost rice's ability to absorb ammonia nitrogen (Sasakawa and Yamamoto, 1978). Fish feed and the rising summertime temperature may be to blame for the declining trend of the DO levels, whereas fish's continuous swimming over trenches and/or rice fields may increase the water's oxygen content by allowing atmospheric oxygen to dissolve into the water (Zajdband, 2011). The lack of chemical fertilizers may have contributed to lower NH_4^+ -N levels, whereas the breakdown of excess supplemental feed was the cause of the higher concentration, regular loading of fecal matters and scooping of soil in search of feeds by fish within the system. A fish-friendly environment was indicated by the contradictory relationship between DO and dissolved CO_2 . However, in S8, the ammonia load was significantly lower, and the CO_2 level remained high, which may be related to the decreased availability of nutrients (Zajdband, 2011). The salinity ranges in the water were appropriate for freshwater aquaculture and within a typical range (Kumar et al. 2018). Total nitrogen (TN) is typically noticeably higher in integrated rice-fish co-cultures than in rice monocultures, suggesting a nutrient-rich environment for rice growth (Li et al. 2021). All N indications, however, converted quickly and toward a lower range in the current scenario. However, the amount of ammonia, nitrate, and nitrite is still a sign of a healthy environment for aquaculture. The physiological processes of aquatic animals, such as ion regulation, respiration, cardiovascular function, and endocrine function, are all impacted by rising trends in nitrite availability, which could pose a hazard to fish and even cause a significant number of fish deaths (Hu et al., 2022). However, anaerobic zones and related denitrifying bacteria may be killed by the ongoing foraging impact of fish in quest of food; these possibilities cannot be completely ruled out.

Studies indicate that the quality of the aquatic ecosystem in the rice-fish coculture system is superior to that of the paddy fields without fish (Bashir et al. 2020), where the structure, services, and operation of the aquatic ecosystem are supported by phytoplankton, the most basic producer of living things in the aquatic ecosystem. The biological and environmental quality of the waterways under study is reflected in the diversity analysis (Katsiapi et al., 2016). In addition to creating chances for consumers, namely zooplanktons and IMCs, the satisfactory density of phytoplankton in the coculture system is a sign of the aquaculture supportive environment by which nutrient cycles have been oriented (Wan et al., 2019). With the exception of S7, which indicated the availability of high decomposition materials due to a larger availability of Euglenoidea (Mussgnug et al. 2010), which may have resulted from an excess of organic debris within the trench area, the dominance of Chloriphyceae also indicated good water health with regard to aquaculture. In addition to this, the high abundance of Bacillariophyceae and Cyanophyceae in S7 and S2 also suggested a high nitrogen availability and/or a favourable environment for the use of nitrogenous wastes (Elder and Horne, 1977).

The aquatic food chain includes the zooplankton community as a crucial component. These species act as a bridge in the food chain, carrying energy from phytoplankton to fish and larger invertebrate predators, which then eat the plankton. Changes in the species composition and abundance can be used to identify the consequences of environmental disturbances. As a valuable ecological indicator for aquatic ecosystems, zooplankton abundance and richness are primarily dependent on parameters linked to water quality, stressors, and disruptions of habitats (physical, chemical, and biological) (Offem et al., 2011). Because they are extremely sensitive to changes in aquatic environments, zooplanktons are useful indicators of trophic levels across time (Ismail and Adnan, 2016; Jeppesen et al., 2011). According to previous research, the predominant rotifera species in each site in the current study belonged to the indicator species that ranged from oligosaprobic to α -mesosaprobic, indicating that the water quality in the IFSs ranged from α -mesosaprobic zone to polysaprobic zone (Li et al. 2021). As a result, integrated farming generally had better water quality, particularly when it came to the population of zooplankton. In addition, fish in the integrated system may be actively consuming the declining zooplankton population as a source of food. However, the chance of predation on fish hatchlings is increased when large-bodied, predatory copepods are available. The presence of cladoceran indicated the presence of excess nutrients within the system (Smirnov 2017). On the other hand, the significant Nauplii availability suggested favorable environmental conditions for the fortification of zooplanktons (Samat et al. 2020).

The findings unmistakably showed that aquaculture in the APCNF's IFS system is a viable economy generator. But inputs, particularly fish seed and supplemental feed, have been shown to play a critical role in improving productivity and reaching the commercial mark through quality control. Nevertheless, the use of exotic fish species, such as Rupchanda, again demonstrates higher production interim efficiency. While the use of naturally occurring and locally manufactured ingredients, such as rice brands, GJM, and DJM, have restricted fish productivity to a certain extent. The amount spent demonstrates the viability of IMC culture despite the productivity losses caused by input mismanagement. Despite the fact that each location has a measurable profit margin because of the high density and diversity of plankton, excellent water quality, and minimal use of artificial or other

chemical inputs. Furthermore, the presence of native fish that are not intentionally targeted in the paddy fields naturally maintains good water quality and creates workable conditions for future initiatives of a similar nature. The inclusion of unusual and predatory creatures should be limited in that scenario, though. Farmers' growing interest and willingness towards learning processes in integrated rice fish farming is a positive sign for its acceptance in the future because they find it to be a very profitable, labor- and effort-efficient procedure when compared to other agricultural approaches (Belton et al. 2017). The rate of expenses, productivity, and profitability of APCNF's IFS-based aquaculture remained much higher than those of the other well-known agroecological rice fish co-culture zones in India (Sathoria and Roy 2022). However, because of the increased return, there may be a chance that tastes will change from rice fish to solely fish (Belton et al. 2017). Additionally, it has been noted that some farmers are becoming increasingly interested in higher fish production, leading them to try more expensive feed supplements, which could jeopardize the long-term viability of the IFS aquaculture method. A further strategy for quickening agroecological transitions could be farmers' interest in regionally favored indigenous food fish or other aquatic species with higher economic value. But in that scenario, it would be necessary to avoid introducing fish species that are predatory, like rupchanda, as they could harm the ecosystem of the natural pond by consume small significantly important indigenous aquatic organisms. Though, initial investment remained the farmers' top concern since they found the expense of building an IFS to be prohibitive, which acted as a major deterrent to their own adoption of this technology.

5. Conclusion

The convergence of fish culture with rice cultivation has garnered increased attention recently, presenting a promising avenue to play a significant role in national economy, decline in wild fish stock and to make fish more accessible to a larger number of rural households. The current study unequivocally affirms the feasibility of rice-fish production as environmentally benign, low-risk supplementary economic activity. To fully capitalize on these advantages, the development agencies should carefully consider and prioritize integration of rice fish farming for the benefit of small and marginal. The study identifies a concerning trend of overuse of certain inputs, such as fertilizers and fish feed, among farmers engaged in rice-fish farming, underscoring the need for improved extension services. Lowering the initial setup cost has been suggested as an additional strategic option to address the low-cost availability of high-quality fish seed, particularly to increase its relevance among small and marginal farmers who have limited access to corpus funds. To fully leverage the potential of rice-fish farming, the government need to overcome obstacles by enhancing extension services, educating, and financially supporting resource poor farmers. Reconsidering land preparation strategies to reduce initial cost and provisioning short-term low-interest loans for earth construction, alongside subsidies for IFS-based rice-fish co-culture may trigger large scale adoption. Close collaboration between researchers and extension agents is essential for effective technology transfer. In co-culture system, fish naturally manage predation needs, promoting ecological synergies, aiding in rice development, and maintaining environmental equilibrium. This system has potential balance agricultural input-output and ecosystem health, with implications for sustainable agriculture on ecological, economic, and social levels. Future research should explore survival rate, optimal fish stocking density and input distribution.

Establishing natural breeding habitats for native fish species requires careful consideration for ecological and economic benefits. Finally, understanding the persistent impact of rice-fish coculture on the aquatic environment and biodiversity, opens up opportunities for furthering the agroecological transition. So, for transfer of recommended fish farming practices at field level, extension person should involve experienced rice-fish farmers in the training and meeting programmes so that they can share their knowledge among fellow farmers. For motivating the farmers to adopt recommended practices, concerted efforts are needed from the government organization so that farmers can get remunerative prices for their product.

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Ayan Samaddar, Research Associate, WorldFish ayan.samaddar@cgiar.org

Arun Padiyar Panemangalore, WorldFish Lead - India a.padiyar@cgiar.org

Sudharsan Maliappan, IWMI-ITC Project Research Officer, IWMI Delhi s.maliappan@cgiar.org

Gulshan Borah, Project Coordinator, IWMI Delhi g.borah@cgiar.org

Alok Sikka, Country Representative - India, IWMI Delhi a.sikka@cgiar.org

Gopal Kumar, Researcher - Agroecology, IWMI Delhi g.kumar@cgiar.org

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