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Economic and social feasibility of small-scale aquaculture ponds operated with the Sun-Oxygen-System

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Abstract

Women are an essential part to a functioning society in Cambodia, raising family and making important contributions to food security. Nevertheless, they suffer from gender inequalities in various areas and especially lack decision-making power. While the country is exposed to an increasing risk of nutritional insecurity, based on decreasing wild fish catches and a poor state of aquaculture, empowering women in the sector of aquaculture can mitigate these risks.

An interdepartmental project launched by the Zurich University of Applied Sciences (ZHAW), the Asian Institute of Technology (AIT) and Smiling Gecko Cambodia has provided training and infrastructure for initially ten women to run their own small-scale aquaculture business. In order to improve oxygen levels in the waters of the fish ponds, an off-grid solution called "Sun-Oxygen-System" (abbreviated SOS) was developed by the ZHAW. The first growth cycle that started in 2020 was carried out without any oxygen enhancing device, whereas in the second cycle, which started mid 2021, the Sun-Oxygen-System was implemented into the ponds.

This thesis presents findings on the different performances of these small-scale aquaculture ponds operated without and with the SOS. It is based on quantitative as well as qualitative research to provide an insight on growth, fish mortality and feed conversion ratio. Furthermore, it contains information on aquaculture and agricultural production. Based on production quantities, the economic viability of the farms was analysed and information on the success of the project was collected.

It was found that the monthly fish weight was higher in cycle 1 while the feed conversion ratio increased from an average of 2.32 in cycle 1 to an average of 3.93 in cycle 2. The decline of the two latter parameters could be primarily attributed to an increased concurrence due to natural reproduction of fish in cycle 2. Mortality decreased from a total of 32.36 % in cycle 1 to 2.7 % in cycle 2. Main fish harvests started in cycle 1 as of month four. In cycle 2 small amounts were continuously harvested during each month, while main harvests took place as of month six. The monthly harvests of small amounts in cycle 2 were possible because fish from cycle 1 remained in the pond. The later harvest in cycle 2 is attributed to slower growth of the fish. After the construction of the ponds the agricultural crops were significantly diversified, and the total production quantities increased by 115 %, which could be attributed to the increased water availability on the farm due to the pond.

Based on sampling of fish and conducted data, no clear results could be obtained regarding the functionality of the SOS. However, it is likely that the technology has contributed to the drastic reduction of the mortality rate in cycle 2.

The analysis of the economic viability revealed that all farmers were able to cover the operational costs and furthermore, generated profits. The average annual profits including agricultural production amounted to 267.3 $. At a total workload of 2 hours per day, the profits correspond to an hourly wage of 0.37 $. The economically most successful farmer reached an hourly wage of 0.77 $, which is just under the minimum wage of a factory worker. One important determinant factor in increasing profitability was identified to not only in increasing agricultural production but also reducing commercial feed cost. Depending on what is included into the financial calculations, the payback period for the capital investment on average ranges between 5.38 to 13.32 years.

The project success assessment revealed that the consumption of fish has increased by 1 day per week and the farmers generally planned to expand their aquaculture and agricultural production in the future. Moreover, they were open to support fellow women farmers in regard to developing their own aquaculture production.

Zusammenfassung

Frauen sind von essenzieller Bedeutung für eine funktionierende Gesellschaft Kambodschas. Sie übernehmen die Verantwortung für die Erziehung der Kinder, sorgen für die Familie und leisten einen wichtigen Beitrag zur Ernährungssicherheit. Dennoch leiden kambodschanische Frauen in verschiedenen Bereichen unter geschlechtsspezifischen Ungleichheiten und ihre Teilnahme an Entscheidungsprozessen ist gering.

Da Wildfischfänge stagnieren und der Zustand der Aquakultur in Kambodscha unzureichend ist, besteht das Risiko, dass die Ernährungssicherheit bald nicht mehr gewährleistet werden könnte. Die Inklusion von Frauen in den Sektor der Aquakultur könnte jedoch ebendieses Risiko vermindern.

Ein interdepartementales Projekt, das von der Zürcher Hochschule für Angewandte Wissenschaften (ZHAW), dem Asian Institute of Technology (AIT) und Smiling Gecko Cambodia lanciert wurde, hat zehn Frauen auserwählt und diese im Bereich der Fischzucht durch verschiedene Workshops ausgebildet. Zusätzlich wurde auf dem Land jeder Frau ein Teich gebaut, in welchem Fische gezüchtet werden können. Um den Sauerstoffgehalt im Wasser der Fischteiche zu verbessern, wurde von der ZHAW das Sun-Oxygen-System (abgekürzt SOS) entwickelt, welches unabhängig vom Stromnetz über ein Solarpanel betrieben wird. Der erste Wachstumszyklus (Zyklus 1), der im Jahr 2020 begann, wurde ohne SOS durchgeführt. Für den zweiten Wachstumszyklus (Zyklus 2), welcher Mitte 2021 begonnen hat, wurde das SOS in alle Teiche installiert. Folglich werden in dieser Arbeit die Erkenntnisse über die unterschiedlichen Leistungen der Aquakulturteiche vorgestellt sowie die Auswirkungen des SOS Systems untersucht. Die Arbeit basiert sowohl auf quantitativer als auch auf qualitativer Forschung. Das Wachstum der Fische, die Überlebensrate und die Futterverwertung wurden analysiert. Außerdem wurden Daten zur Produktion von Fisch und sonstigen landwirtschaftlichen Produkten aufgenommen. Anhand der resultierenden Produktionsmengen konnte die Wirtschaftlichkeit jedes Betriebes analysiert werden. Zudem wurden auf der Basis von standardisierten Fragen Informationen über den Erfolg des Projektes gesammelt und ausgewertet.

Das monatliche Durchschnittsgewicht der Fische lag in Zyklus 1 höher als in Zyklus 2. Die durchschnittliche Futterverwertung war ebenfalls besser in Zyklus 1 mit einem Durchschnittswert von 2,32, welcher in Zyklus 2 auf 3,93 anstieg. Da sich während Zyklus 2 noch Fische aus Zyklus 1 im Teich befanden und sich diese unkontrolliert reproduziert haben, kann die intraspezifische Konkurrenz als Grund für die Verschlechterung der beiden Parameter zugeordnet werden. Zudem wurden die Werte auf der Basis der gelieferten Fingerlinge für den zweiten Zyklus berechnet. Die Biomasse lag aber, basierend auf der

natürlichen Reproduktion, höher, weshalb die Werte aus Zyklus 2 nicht repräsentativ sind. Die Mortalitätsrate hat sich von 32,36 % in Zyklus 1 auf 2,7 % in Zyklus 2 reduziert. Die Haupternte der Fische begann in Zyklus 1 ab dem vierten Monat. In Zyklus 2 jedoch wurden seit Beginn an kontinuierlich kleine Mengen an Fischen geerntet, während die Haupternte im sechsten Monat stattfand. Die kontinuierlichen Ernten in Zyklus 2 bestehen aus Fischen, welche noch aus Zyklus 1 im Teich verblieben sind. Die spätere Ernte in Zyklus 2 kann auf das langsamere Wachstum der Fische aufgrund der erhöhten Konkurrenz zurückgeführt werden.

Nach dem Bau der Teiche haben die Bäuerinnen ihre landwirtschaftlichen Kulturen erheblich diversifiziert und die Gesamtproduktionsmengen in Zyklus 2 um 115 % gesteigert. Dies ist primär auf die erhöhte Wasserverfügbarkeit aufgrund des Teiches zurückzuführen.

Anhand der gesammelten Daten aus Zyklus 1 und Zyklus 2 konnten keine eindeutigen Ergebnisse hinsichtlich der Effektivität des SOS gewonnen werden. Es ist jedoch wahrscheinlich, dass die Technologie zu der drastischen Verringerung der Sterblichkeitsrate in Zyklus 2 beigetragen hat.

Die Analyse der wirtschaftlichen Rentabilität ergab, dass alle Frauen in der Lage waren, ihre Betriebskosten zu decken. Darüber hinaus konnten auch alle Frauen Gewinne erzielen. Die durchschnittlichen Jahresgewinne einschließlich der landwirtschaftlichen Produktion betrugen 267,3 $. Bei einer Gesamtarbeitszeit von zwei Stunden pro Tag entspricht der Gewinn einem Stundenlohn von 0,37 $. Die wirtschaftlich erfolgreichste Bäuerin erreichte einen Stundenlohn von 0,77 $, was knapp unter dem Mindestlohn eines Textilfabrikmitarbeiters liegt. Die Erhöhung der landwirtschaftlichen Produktion konnte als einen entscheidenden Faktor identifiziert werden, wenn es darum geht, die Gewinne zu steigern. Zusätzlich hat auch die Menge an zugekauftem kommerziellem Futter einen hohen Einfluss auf die Betriebskosten und so auf die Wirtschaftlichkeit. Abhängig davon, welche Betriebszweige mit in die finanziellen Berechnungen eingeflossen sind, liegt die Amortisationszeit für die Kapitalinvestition im Durchschnitt zwischen 5,38 und 13,32 Jahren.

Der Projekterfolg konnte daran gemessen werden, dass der Fischkonsum der Bauernfamilie im Durchschnitt um einen Tag pro Woche gestiegen ist. Auch äusserten die Bäuerinnen einstimmig den Wunsch, dass sie ihre Aquakultur und landwirtschaftliche Produktion in Zukunft expandieren möchten.

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Abbreviations

WiA	Woman in aquaculture
WLF	Woman leader farmer
SOS	Sun-Oxygen-System
FCR	Feed conversion ratio

1 Introduction

1.1 Cambodia

Located in Southeast Asia, Cambodia is a country bordering Thailand, Laos, and Vietnam. According to the latest data, the total population counts up to 16.719 Mio. citizens (World Bank, 2020b). For the first time in history, the country met the criteria to graduate from the category with the status of “least developed country” (UN, 2021). Nevertheless, Cambodia still faces enormous challenges, which are further intensified through the COVID-19 crisis (World Bank, 2021c) and climate change. As the World Bank Group (2021) states, Cambodia is highly vulnerable to the impacts of climate change due to its dependency on climate-sensitive sectors such as agriculture, water resources, forestry, fisheries, tourism etc. These sectors form the critical foundation of its economic growth and support the livelihoods of a significant majority of its population. According to the Human Development Report (2020), 37.2 % of the population live in multidimensional poverty while an additional 21.1 % of the population are classified as vulnerable to multidimensional poor.

1.1.1 Agriculture

Agriculture is a dominant sector in the economy of Cambodia with a contribution of 22.379 % to the gross domestic product (World Bank, 2020a). One third of the population is directly employed in the agricultural sector (O’Neill, 2021). 70 % of the cultivated land is covered by rice crops (ADB, 2021b), which is also the most important staple food of the population and thus a direct factor in attaining food security (CDRI, 2011). Even though Cambodia has seen rapid improvements in the reduction of hunger since 2000, the country is still seriously affected by it (von Grebmer et al., 2017). Especially the rural population, which comprises about 75% of the entire population (World Bank, 2020b), suffers regularly from severe malnutrition. This is partly caused by the lack of knowledge on good agricultural practices of smallholder farmers (Koroma, 2002). The crop production is predominantly rainfed, which in the case of rice results in only one crop per year (CDRI, 2011). Therefore, the rice yields are lower than in neighbouring countries like Vietnam (ADB, 2021b). This yield gap could be closed by changing to irrigated cultivation methods, whereby the production could increase around 40 % (ADB, 2021b).

1.1.2 Fishery

With the Tonle Sap being the most productive lake worldwide located in Cambodia, freshwater fish naturally is the most important source of animal protein for the population (Baran, 2005) and the main staple food after rice (CDRI, 2011). Depending on the geographic location, aquatic animals count up to 81.5 % of the total animal protein intake (Hortle, 2007) and about

35 % of the total households participate in fishery (CSES, 2020). Over the last two decades, inland water capture production in Cambodia has almost doubled with yields of 0.34 Mio. tons in the year 2000 to 0.54 Mio. tons in 2018 (FAO, 2020). This data may indicate that there is no obvious reason for concerns regarding the fish resources, yet catches have stagnated in recent years. To assess the status of the inland fishery in further detail, industrial fish catches were monitored over the period from 2000 to 2015. The analysis revealed that 78 % of the species caught in total were in significant decline and that the average size of the fish is decreasing, while the number of immature fish captured increased (Ngor et al., 2018). Although clear evidence of a decrease of the overall fish catches is missing, Baran & Myschowoda (2008) point out that a measurable decline is only a matter of time, as the number of fish per catch have already been decreasing. This suggests that fish stocks are being overexploited.

However, the decrease is not only due to overfishing, but also due to hydrological changes in the Cambodian floodplains that emerge through the impacts of upstream hydropower dams (IFReDI et al., 2013). The dams do not only act as physical barriers to migratory fish species and hinder their access to spawning grounds (IFReDI et al., 2013), but they also drastically alter the natural water flow of the Mekong river, which in return influences the flood pulse of the Tonle Sap lake (ADB, 2005). Over the last 60 years, the flood season has decreased up to 40 days depending on the region, whereas minimum and maximum water levels have dropped by 1.06 m (Chua et al., 2022). In this case, however, the authors not only mention the dams as the reason for the changes in the flood characteristics of the river, but also discuss other factors such as increased irrigation infrastructures and sand-mining operations (Chua et al., 2022). Nevertheless, far more hydrological dams are in planning, and it is evident that they will further decrease the fish supply. Depending on the dam development scenario, predictions estimate a reduction of freshwater fish supply of up to 34 % by 2030, which will have a severe impact on the nutritional security in the country (IFReDI et al., 2013).

In addition, the dams exacerbate drought conditions (Eyler et al., 2022) in a country that is classified as extremely vulnerable to climate change (ADB, 2021a). Considering the fast rising population (World Bank, 2021b) and in consequence the growing demand for food resources, a decline in wild fish stock seriously threatens food security in the country.

1.1.3 Aquaculture

A measure to reduce the pressure on the freshwater fish stock is aquaculture, because it allows to meet the demands of animal protein and thereby secures the food supply. The production within the aquaculture sector has increased considerably over the last 18 years: from14’430 tons in 2000 to an amount of 254’050 tons in 2018 (World Bank, 2018a). However, in the same year, Vietnam produced 4’153’232 tons of fish (World Bank, 2018b), which is 16 times more than in Cambodia. This illustrates that there is still much room for improvement in Cambodia’s aquaculture sector.

Joffre et al., (2021) assessed the state of aquaculture in Cambodia by surveying a total of 1204 farms. Their research revealed that aquaculture in the country is facing a variety of challenges that cannot currently mitigate declining wild freshwater fish yields (IFReDI et al., 2013). Foremost, farmers are predominantly using trash fish to feed their fish, which is problematic as it directly competes with human consumption and relies on wild fish yields. It was estimated that the farms included in the research used an amount of 13’400 t of trash fish in the survey year (Joffre et al., 2021).

Furthermore, Cambodia is highly dependent on neighbouring countries for their egg and fingerling supply, which makes the sector vulnerable, because there is almost no quality control. Economically, the sector faces the challenge that imported or wild caught fish is cheaper than domestically farmed fish. Consequently, Cambodian fish remains unsold. To achieve a competitive market price, the cost for feed should be around 0.5 $/kg. However, currently the price is set at 0.61.-0.87 $/kg. (Joffre et al., 2021)

The main fish species produced is Pangasius, which accounts for 61 % of total fish production, followed by giant snakehead with 25 % and striped snakehead with 7 %. The latter two are carnivorous fish. As catches from fishery are declining and wild caught fish competes with human consumption, it should be highlighted that feed alternatives need to be promoted and a shift towards farming non-carnivorous fish species like tilapia, which can be fed with plant-based diet, is necessary. (Joffre et al., 2021)

1.2 Gender inequalities in Cambodia

The loss of development due to inequalities between the genders in Cambodia is significant: With a Gender Inequality Index of 0.474, the country classifies on position 117 out of 162 countries, which indicates that gender equality is far from being achieved (UNDP, 2020). With 15.1%, the participation rate of a secondary education for women is lower than that for men as their rate amounts to 28.1% (UNDP, 2020). The same holds true for adult literacy (reading and writing simple messages): 77.1% of all women are literate and 87.2% of all men (CSES, 2020). These inequalities result in a lower ability for women to defend and advance their legal rights (ADB, 2015).

Women participate with 40.9 % in paid employment work, as opposed to men with 53.1 % in the same category (CSES, 2020). This difference can be explained by the excessive amount of domestic and care work that women are undertaking, which constrains their option of taking on paid work (ADB, 2015). Women are expected to care for the family and run the household. As a consequence, they carry out an average of 3.5 hours of unpaid work per day more than men (ADB, 2015).

The primary sector of employment for both sexes is agriculture. 35.5 % of the totally employed population works in the agricultural sector. The rate of women's participation in the field is at 38 % which is higher opposed to men at 33 % (CSES, 2020). This highlights the evidence that women are important contributors to food security in the country. However, they struggle to receive economic benefits and face a high degree of inequalities: Women experience limited access to resources like land, extension services, financial services, markets, knowledge, and technology (ADB, 2015). Especially when it comes to land ownership, women are in great disadvantage. Although they account for 47.3 % of the total agricultural labour force, they only own 11.7 % (CSES, 2020) of total plots for agricultural activities, while men own 88.3 % (FAO, 2010).

Out of economic necessity, women are increasingly migrating to find paid employment in the industrial sector, primarily in the garment and footwear industry. More than 90 % of these factory workers are women, largely coming from rural areas with a low level of education. Yet, benefits for women working in the garment sector are marginal, due to the low wages (ADB, 2015). Considering the shift of women from household-based activities to activities in the industrial sector, the overall food security may be threatened.

1.2.1 Women's activities in fishery and aquaculture

The contribution of women in fishery and aquaculture is often overlooked, even though they significantly contribute to the protein availability of their family (Harper et al., 2013). In small-scale fisheries of developing countries women account for 50 % of the total workforce (FAO, 2020). They carry out fishing activities closer to their household, mostly nearshore, while men focus on offshore fishing (Kwok et al., 2019).

A study that identified different perceptions of gender dynamics in small-scale fisheries of the Tonle Sap Lake revealed that contrary to women that perceive fishing as a part of their work, only few men acknowledged their role. For most men, nearshore fishing does not count as a form of “real fishing”. This finding clearly highlights the fact that women’s contribution is being undervalued, limiting their active participation in management activities. This is being reinforced by the phenomenon that nearshore caught fish are smaller, resulting in less income for women, thus confirming men’s belief of women’s insignificant contribution in the sector. (Kwok et al., 2019)

With regard to aquaculture, women are active in all sections of the value chain. However, they are primarily working in small-scale production, post-harvest processing, value addition, marketing and sales (Brugere & Williams, 2017). The disadvantages that women face in the agricultural sector are transferable to the sector of aquaculture. However, the gender gap in aquaculture has received much less global attention (Williams et al., 2010) and data on women’s participation is not sufficiently available (Brugere & Williams, 2017).

Compared to men, women are paid lower or remain unpaid for the same work and/or typically perform tasks of lower status. As stated by Brugere & Williams (2017), when production intensifies, women’s engagement drops and only rarely they attain access to leadership positions. This is not only linked to the lower educational status of women but also based on the conditioning by society (Brugere & Williams, 2017). Figure 1 illustrates different factors that shape women’s positions in aquaculture (Kruijssen et al., 2018).

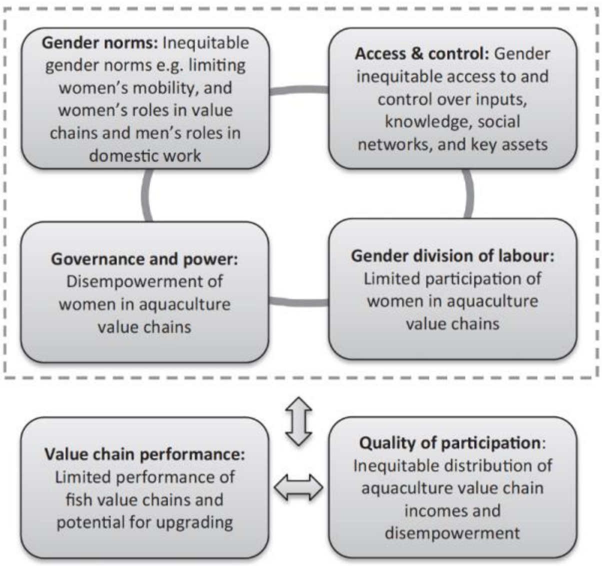

Figure 1: Factors shaping gender relations and outcomes for aquaculture value chains (Kruijssen et al., 2018)

One step to move towards gender equality in the sector is the development of gender-sensitive fisheries and aquaculture policies, which are still in the process to be made (FAO, 2020).

1.2.2 Empowering women through aquaculture

In light of the omnipresent gender inequalities in the aquaculture sector, it is important to empower women's participation. Engaging them in aquaculture can improve food security and bring a positive impact on an individual but also societal level. A project that was launched in Nepal to promote women's activity in aquaculture and improve rural food security has proven the matter to be successful.

A group of 26 women were supported in constructing a pond and were provided training on fish farming. Taking on aquaculture has improved the amount of animal protein intake for the family. Since 40 % of the harvest was consumed and 60 % of the production was sold, this resulted in a financial income. (Bhujel et al., 2008)

Especially in cases where men leave the household and migrate for work, small-scale aquaculture can have the power to help women sustain their livelihood (Williams et al., 2010). Nonetheless, it is worth noting that taking on aquaculture activities in addition to their other responsibilities and duties may result in an augmented workload, thus increasing the burden on women (Williams et al., 2010).

On the basis of the "Strategic Planning Framework (SPF) for Fisheries" of the Kingdom of Cambodia, Leakhena et al., (2018) has gathered a list of recommendations to improve women's participation in aquaculture. These include:

- providing special training courses on specific subjects to women who are unemployed
- increase farm facilities (fishponds)
- strengthen and build knowledge on aquaculture
- promote aquaculture development via social media

1.3 The Project: Sun-Oxygen-System - Energy efficient fishpond aeration enhancing integrated small-scale farming in Cambodia

As a result of Cambodia's challenges regarding declining capture fish yields, the poor state of the present aquaculture as well as the gender inequalities, this project was launched to engage women in aquaculture with the aim to develop an economically and socially sustainable small-scale aquaculture production. It arose from a collaboration between the Zurich University of Applied Sciences (ZHAW), the Asian Institute of Technology (AIT) and the NGO Smiling Gecko Cambodia and is built on foregoing projects. Funding came from REPIC, an interdepartmental platform of different federal offices of Switzerland. The project is supported by Ram C. Bhujel (AIT), who is a leading scientist in this research field.

1.3.1 Smiling Gecko

The NGO Smiling Gecko was founded in 2012 and started its operations in 2014. It consists of different cluster projects that are interlinked and focus on poverty alleviation through education and employment (SGC, 2022). One of these cluster projects is a fish farm that started in 2018 and established a hatchery and grow-out system for the production of tilapia (Tschudi, 2019a). It was developed with the help of the Zurich University of Applied Sciences and has become well-known among governmental institutions in Cambodia. In 2021, the Smiling Gecko aquaculture department produced 20 t of tilapia (T. Soeun, 2022). For 2022, they are aiming to reach a production mass of 35 t (T. Soeun, 2022). Furthermore, they will be doubling their fingerling production from 1 Mio. in 2021 to 2.2 Mio. in 2022 (S. Y, 2022). Therefore, Smiling Gecko plays a central role in the success of the project. They not only transferred important knowledge through educational workshops on different aspects of fish farming and marketing but also provided high quality fingerlings for the woman leader farmers.

1.3.2 Woman Leader Farmers and key features

The project is based in the province of Kampong Chhnang nearby the NGO Smiling Gecko. It consists of 10 women smallholder farmers (Woman Leader Farmers), that were recruited in 2020. Thereafter, a pond was constructed on each of their agricultural lands. The pond is used to produce fish, which can improve the supply of food for the Woman Leader Farmers (WLF) as well as their families and generate income. Additionally, the pond helps to create a more diverse and resilient production system, acting as a reservoir to store rain water, which can be used to irrigate agricultural crops (Tschudi et al., 2019).

1.3.3 Sun-Oxygen-System

The key element of the project is the Sun-Oxygen-System (SOS). It is a project-specific off-grid tool that was developed by the Zurich University of Applied Sciences to increase oxygen levels in small-scale aquaculture ponds, since low oxygen levels are the main limiting factor of productivity in small-scale aquaculture. Furthermore, small-scale farmers usually lack appropriate technologies to increase oxygen levels in their ponds and do not necessarily have access to electricity nor cost intensive generators that run on polluting fossil fuels. The SOS is a technical device that addresses the foregoing problems for operators of small-scale aquaculture ponds. The mechanism of the SOS functions as follows: a pump that runs on solar energy enhances the circulation of the water inside the pond during the day. Oxygen that is produced by algal photosynthesis in the top layer of the pond is being mixed with underlying layers. This leads to a better distribution of oxygen and can result in an improved biomass production and feed conversion ratio. The system is unique as it can be built from simple and easily available materials and runs on renewable energy. (Tschudi, 2019b)

Different designs of the system have been tested since 2020 on-site in Cambodia. The most effective design has shown to increase yields up to 55.6% while profitability increased by 18.5-19.9 % compared to ponds operated without aeration. (Tschudi et al., 2021). However, the pump of the first tested SOS version showed inefficient utilization of the available power generated by the solar panel. In order to improve the efficiency, further pumps have been examined in a bachelor thesis by Cyrill Vuillemin. A pump that was capable of using more than 90 % of the available energy, contrary to the existing pump that could only use about 40 % of the energy, was tested and found to be working well (Vuillemin, 2021). Therefore, the SOS was updated and integrated into the ponds of the women leader farmers with the newly tested pump.

1.3.4 Sustainability of the project

The sustainability of the project can be justified by a multitude of factors as it aligns with 9 out of the 17 Sustainable Development Goals (SDG) from the United Nations. Foremost, SDG 1 (no poverty), SDG 2 (zero Hunger), SDG 8 (decent work and economic growth) and SDG 14 (climate action) are achieved by the pond that provides an increased food production and contributes to a better resilience of the system. This can help to improve food security and mitigate impacts of climate change. The inclusion of women and the educational program promotes SDG 4 (quality education), SDG 5 (gender quality) as well as SDG 10 (reduced inequalities). Moreover, SDG 12 (responsible consumption and production) is being ensured by the choice of fish species. Tilapia can be fed 100 % vegetarian, which, unlike most other species, means that production does not rely on fishmeal. Therefore, SDG 14 (life below water) is also being addressed. Finally, SDG 7 (affordable and clean energy) is accomplished through the SOS relying on solar energy, thus reducing the dependency of fossil fuels. (Tschudi et al., 2019; UN, 2022)

1.3.5 Status of project

After the recruitment of the WLF in 2020 and the construction of the pond, the first cycle of growing fish started. It was characterized by an eager participation of most WLF and successful selling of fish. However, total mortality was high with about 32 %. For cycle 2, the SOS was implemented. It should lead to a decrease of fish mortality and overall increase efficiency of the pond operation.

1.4 Objective of the study

The aim of the thesis "Economic and social feasibility of small-scale aquaculture ponds operated with the Sun-Oxygen-System" is to examine the farms from an economic and social point of view and to compare the differences between the two cycles, not only in order to verify the success of the small-scale farms but also the SOS in its practical application. For this purpose, the author of the thesis was on-site from the start of the second cycle and collected comprehensive data in form of surveys throughout the course of six months. This data serves as a basis to compare the second cycle with existing data of the first cycle. Finally, the thesis provides information on the variations regarding fish growth, feed efficiency, and fish mortality between the two cycles. This information acts as a basis to determine whether the integration of the SOS in the second cycle contributes to an increased production volume. A profit and loss calculation of the aquaculture operations verifies the economic viability. Ultimately, based on a qualitative assessment, the thesis attempts to determine whether the project has had a positive impact on the farmers and identifies improvement measures.

2 Methodology

In order to explore the economic and social feasibility of small-scale aquaculture ponds operated with the SOS, a trial was conducted from December 2020 until March 2022. It involved eight project participants (WLF) and their ponds. During the timespan of the trial, two rearing cycles were carried out. Cycle 1 started in December 2020 by stocking the first batch of tilapia into all the ponds and was completed without any aeration technology. In September 2021, an SOS for each WLF was constructed and installed into the pond. Thereafter, in October 2021, cycle 2 started by adding a new batch of tilapia and an SOS.

The two rearing cycles (cycle 1 without SOS, cycle 2 with SOS) set the basis of this thesis. The research method on-site combined qualitative and quantitative data collection. In order to determine the differences between the two cycles, data regarding fish and agricultural production was regularly documented and different surveys were conducted over the timespan of the two cycles.

2.1 WLF

In order to be recruited as a WLF, the women had to fulfil certain requirements. They had to have a low household income, not be indebted and be owner of at least a plot of 1000 m^2 of land, which had to be located close to their house. Furthermore, technical criteria included basic writing and math skills for record keeping, ability to use social media and basic economic understanding. Their status in the local community was also considered in the recruitment process. (Tschudi et al., 2019)

Two WLF decided not to participate anymore, thus eight out of the initial ten WLF are represented in this paper (Scott, 2022a). Basic information on each WLF as well as their pond location can be found in the Appendix A. The WLF have been categorized in numbers to facilitate organization and communication. This is being followed throughout the thesis.

Five educational workshops, which were developed in collaboration with Dr. Ram Buhjel from the AIT, provided the WLF with the necessary knowledge in order to run their small-scale aquaculture ponds. The workshops covered the following topics (Scott, 2022b):

1. water management, pond health, pond safety
2. fish feed, storing feed, feed planning, feeding fish, producing feed
3. fish health, healthy fingerlings
4. marketing
5. harvesting, processing

2.1.1 Ponds

On the land of each WLF, a pond with a width of 11.6 m, a length of 21.6 m and a water volume of 300 m^3 was constructed in 2020. Due to the sandy structure of the soil, each pond was fitted with a pond liner. Apart from rainwater that filled the pond, water was also pumped into the ponds from sources close by.

2.1.2 Cycles

Contrary to cycle 2, the SOS was not yet implemented into the ponds. Furthermore, the two cycles differ in terms of fish stocking and feed supply, which is illustrated in Table 1.

In cycle 1, each WLF was supplied with the same number of fingerlings. However, as a result of different stocking dates, their weight varies between 12 g to 26 g. For cycle 1, the WLF were given two different types of pellet feed (3 mm and 5 mm) with a protein content of 30 % (T. Soeun, 2022).

Before the pond was stocked with new fish for cycle 2, the sludge of the cycle 1 was removed from the bottom of the pond by pumping it directly onto the crops to fertilize surrounding crops. Moreover, the SOS were installed in each pond prior to the start of cycle 2.

In cycle 2, all the ponds were stocked with fingerlings of uniform size on the same date. Due to different amounts of remaining fish (biomass) in the pond from cycle 1, the number of supplied fish for cycle 2 varies in between the WLF. To estimate the remaining biomass, fish were fed ad libitum prior to cycle 2. According to the total feed intake, the remaining biomass in kg was estimated individually for each WLF with the following formula:

$$biomass\ (kg) = \frac{mf(kg) * 0.5}{(\frac{f_{rate}}{100})} \qquad (1)$$

$mf(kg)$ = maximum feed load in kg (fish fed ad libitum)

f_{rate} = ideal feeding rate in % of bodyweight

In cycle 2, the WLF were supplied a different feed with a lower protein content of 22 % and only one pellet size (5 mm) (T. Soeun, 2022). Furthermore, the WLF were educated and encouraged to produce additional supplement feed with on-farm ingredients for cycle 2.

Table 1 Input of fish and feed for cycle 1 and cycle 2 for each WLF. Remaining biomass in cycle 2 consists of the assumed remaining fish from cycle 1 and influenced the number of fingerlings that were supplied for cycle 2.

Cycle 1	**WLF 1**	**WLF 2**	**WLF 3**	**WLF 4**	**WLF 7**	**WLF 8**	**WLF 9**	**WLF 10**
Number of fingerlings (pcs)	1230	1230	1230	1230	1230	1230	1230	1230
Weight per fingerling (g)	12	12	12	20	12	12	26	20
Commercial feed provided for cycle (kg)	575	487.5	600	600	450	150	275	575
Cycle 2	**WLF 1**	**WLF 2**	**WLF 3**	**WLF 4**	**WLF 7**	**WLF 8**	**WLF 9**	**WLF 10**
Remaining fish (biomass) from cycle 1 (kg)	253	409	253	585	72	0	0	426
Number of fingerlings (pcs)	1300	1300	1300	400	1300	1300	1000	1000
Weight per fingerling (g)	20	20	20	20	20	20	20	20
Commercial feed provided for cycle (kg)	600	600	600	600	600	600	600	600

2.1.3 SOS

The SOS was developed by the ZHAW in the beginning of 2020. Five different designs were then tested at SGC. Based on data collection which demonstrated the potential of the technology, the most effective design was selected and implemented into the ponds of the WLF. The main components of the system, illustrated in Figure 2, consist of a solar panel, a pump, a pipe as well as the electrical components (cables, controller, step-down module). To reduce the risk of theft, the system was designed to be floating on the surface of the pond. Four barrels that are attached to each corner of a metal frame, which holds all the components together, keeps the system afloat. To further improve the efficiency of the SOS, the system was modified by exchanging the original pump (Jebao Stream RW-20) with a pump (IPX8) that is capable of using the supplied energy more efficiently. The new pump was not tested beforehand and in the course of cycle 2, frequent breakdowns occurred. Hence, towards the end of cycle 2, pumps were exchanged back to the original type that proved to work well.

Figure 2 The SOS in its basic set-up (Konrad, 2021)

2.2 Operational data

The data that set the basis for this thesis derives from two different types of surveys that were conducted regularly over the timespan of cycle 2. Data from cycle 1 was included in the thesis, although it was not collected by the author. Figure 3 illustrates the data collection with the surveys according to the cycles.

The surveys were developed in English. However, the women leader farmers do not have knowledge of the English language. Due to this, the conduction of the surveys was always done in company of a person that spoke English as well as Khmer (Cambodian language) and could translate the questions.

2.2.1 Baseline Survey

Based on data that was collected during cycle 1, the baseline survey for cycle 2 was developed. To examine the changes that occurred between cycle 1 and cycle 2, the questions used for the data collection of cycle 1 were adopted in the survey for cycle 2. To assess each farm in more detail, further questions were included into the survey of cycle 2. The baseline survey provides qualitative and quantitative data on the following areas of each WLF and their families: health status, consumption habits, aquaculture production, agricultural production, livestock production, farm management and satisfaction regarding livelihood as well as the project.

The initial baseline survey from cycle 1 was conducted in November 2020 before the start of cycle 1. The first baseline survey of cycle 2 was conducted in September 2021, before cycle 2 started. The same survey was conducted a second time in March 2022 while cycle 2 was still going on.

2.2.2 Follow-up Survey

The follow-up survey is less comprehensive than the baseline survey. It was conducted during cycle 1 already, but similarly to the baseline survey, it was further developed for cycle 2. It recorded data regarding fish production (harvest, sales, consumption and mortality), feed management, pond management, agricultural production, livestock production and the functioning of the SOS. It was conducted every two weeks over the course of five months from November 2021 to March 2022, which resulted in nine follow-up surveys.

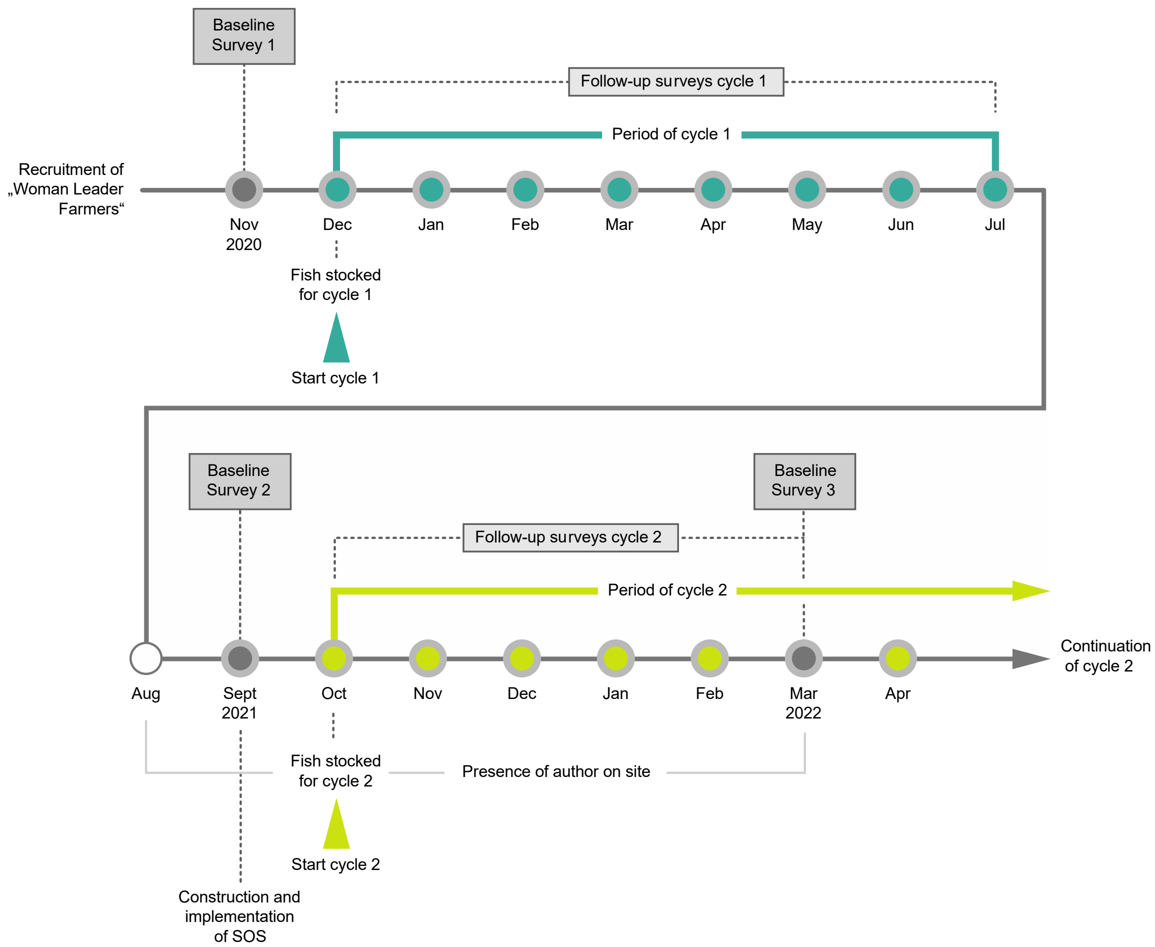

Figure 3 Timeline of the trial since the recruitment of WLF. Cycle 1 is indicated with the blue dots. Cycle 2 is indicated with the green dots. The surveys are represented in the grey boxes.

2.2.3 Fish size

The fish size was monitored once a month for each cycle. Fish were caught with a cast net, transferred to a smaller net and weighed with a portable hanging scale. 5x10 fish were weighed, which resulted in a sample of 50 fish per month and WLF. To obtain more precise data, the sample size was increased to a total of 200 fish in the last month of the survey period in cycle 2. The measurements were continuously recorded in a book and transferred in form of an image by Telegram messenger.

2.3 Evaluation of data

All the data was continuously recorded in Excel. The calculations for the economic evaluations were done in Excel while data visualization was done with ggplot in R Studio.

Evaluating the complete data set would go beyond the scope of this thesis. Therefore, the evaluation only focused on data that was necessary to answer the objectives of this paper. Remaining data will provide valuable information for further research. Figure 4 illustrates which type of data was derived from which survey.

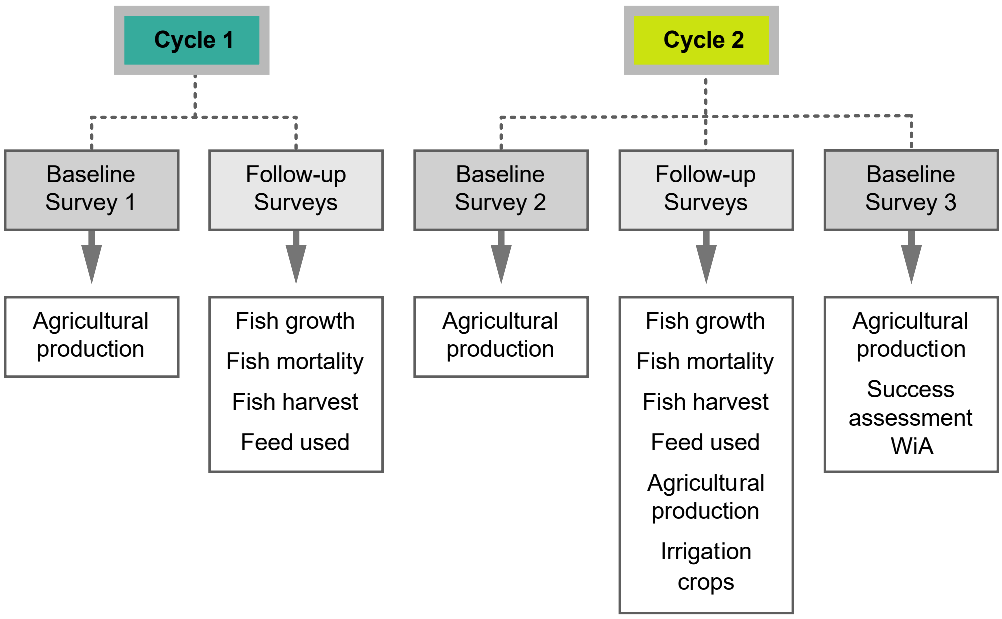

Figure 4 Overview of evaluated data per cycle and survey

2.3.1 Feed conversion ratio

The calculations regarding the feed conversion ratio are solely based on the fish that were supplied for each cycle by Smiling Gecko. Neither does it include the remaining biomass from cycle 1, nor the naturally reproduced offspring.

Through the follow-up surveys of cycle 1 and cycle 2, the number and weight of fish that have left the pond (mortality, consumption, selling) were recorded on a regular basis. As a result, the standing stock (fish remaining in the pond) could easily be determined.

$$N_{remaining} = N_{start} - (N_{dead} + N_{sold} + N_{consumed}) \quad (2)$$

$N_{remaining}$	= number of fish remaining in pond
N_{start}	= number of fish in pond at the start of project
N_{dead}	= number of dead fish
N_{sold}	= number of sold fish
$N_{consumed}$	= number of consumed fish

Furthermore, data on feed use was documented. This data laid the foundation for the calculations of the weight gain of the different categories, which is necessary to calculate the FCR.

$$tWg_{dead} = tW_{dead} - (W_{start} * N_{dead}) \quad (3)$$

tWg_{dead}	= total weight gain of dead fish in kg
tW_{dead}	= total weight of dead fish in kg
W_{start}	= weight per fish (fingerling) at start of cycle in kg
N_{dead}	= number of dead fish

$$tWg_{consumed} = tW_{consumed} - (W_{start} * N_{consumed}) \quad (4)$$

$tWg_{consumed}$	= total weight gain of consumed fish in kg
$tW_{consumed}$	= total weight of consumed fish in kg
W_{start}	= weight per fish (fingerling) at start of cycle in kg
$N_{consumed}$	= number of consumed fish

$$tWg_{sold} = tW_{sold} - (W_{start} * N_{sold}) \quad (5)$$

tWg_{sold}	= total weight gain of sold fish in kg
tW_{sold}	= total weight of sold fish in kg
W_{start}	= weight per fish (fingerling) at start of cycle in kg
N_{sold}	= number of sold fish

$$tWg_{standing} = tW_{standing} - (W_{start} * N_{standing}) \quad (6)$$

$tWg_{standing}$ = total weight gain of standing stock (fish remaining in pond) in kg

$tW_{standing}$ = total weight of standing stock in kg

W_{start} = weight per fish (fingerling) at start of cycle in kg

$N_{standing}$ = number of fish remaining in pond (standing stock)

The values of the different categories of weight gains then led to the required values for the FCR calculation for each WLF.

$$\frac{f(kg)}{tWg_{dead} + tWg_{consumed} + tWg_{sold} + tWg_{standing}} \quad (7)$$

tWg_{dead} = total weight gain of dead fish in kg

$tWg_{consumed}$ = total weight gain of consumed fish in kg

tWg_{sold} = total weight gain of sold fish in kg

$tWg_{standing}$ = total weight gain of standing stock in kg

$f(kg)$ = feed in kg

2.4 Agricultural production

To illustrate the agricultural production, data from baseline survey 1, 2 and 3 were compared with each other. Furthermore, data on the pond as a source of irrigation was analysed to verify the assumption that the pond has a positive effect on the agricultural production. This data was collected in the follow-up surveys.

2.5 Economic viability

The analysis of the economic viability is based on three different parameters, which include: Seed funding (CapEx) for the construction of the pond and the SOS, the operational cost (OpEx) that include feed and fingerlings and the income through the aquaculture production as well as the agricultural production. The aquaculture production consists of the effectively sold fish during the trial and is derived from the follow-up survey. Furthermore, it includes the potential income of fish that remained in the pond (standing stock). For the calculations it was assumed that the fish reached 200 g at the point of harvest, since this is the average weight at which the WLF have been selling their fish. The agricultural income derives from the two baseline surveys of cycle 2. The information on actual prices for fish and agricultural products was provided by Theary Soeun from Smiling Gecko.

In order assess the profitability of these small-scale aquaculture farms, the average of all WLFs was calculated. Then, the profits were determined, based on different scenarios:

- aquaculture as a source of income
- aquaculture and agriculture as a source of income
- aquaculture and agriculture as a source of income with a reduction of the operational cost

Finally, the payback period of the seed fund without and with interest rate was calculated.

2.6 Success assessment

In order to assess the impact of the project on the WLF, they were asked to give categorical answers (No, Rather No, Rather Yes, Yes) to following statements:

- The pond has made a positive impact in my life.
- I am feeling confident about mine and my family's future.
- I am planning to expand my agricultural business.
- I am planning to expand my aquaculture business.
- I would recommend the project to other women.
- I would support other women in doing the same.
- I feel overburdened to learn about fish, pond and aquaculture management.
- I require more support regarding pond and fish production.

Furthermore, the weekly consumption of fish was included into the success assessment and derives from the baseline surveys.

3 Results

3.1 Aquaculture production

3.1.1 Fish size and weight gain

Figure 5 shows the average fish weight over the first five months during the two cycles. Each box represents all WLFs and is built from 80 data points (per WLF a sample of 5x10 fish). According to the data, the growth of the fish has performed better in cycle 1. Yet, concluding that the growth performed worse in cycle 2 may be incorrect, due to the difficulties in data collection that are based on the differences of the cycle set-ups.

In the first three months of growth, the increase of fish weight is comparable amongst the two cycles. In month four however, the fish weight decreases in both cycles. This can be attributed to the fact that the WLF started to harvest the first batches of fish that reached the biggest size, especially in cycle 1, which is illustrated in Figure 8. This led to a reduction in the average fish weight. The sudden decrease of weight in cycle 2 though, is based on other reasons, foremost because the WLF did not yet start to harvest large batches of fish as of month four, which is visible in Figure 9. The primary reason for the deviation is a change in the method of the sample collection. Whilst assessing the average weight of fish in cycle 1 was fairly easy, due to an even size of the fish, assessing the average fish weight in cycle 2 turned out to be more complicated, since a share of fish from cycle 1 had remained in the pond and started to naturally reproduce while cycle 2 was ongoing. This led to a high variability of fish weight and difficulties regarding the identification of the individuals that were stocked for cycle 2. In order to obtain accurate data, only the biggest fish were selected for the sample. However, in month four, all fish caught (fish from cycle 2, offspring from cycle 1) were included into the sample, which led to the significant decrease of the average fish weight. Furthermore, during cycle 2, it is likely that fish remaining from cycle 1 were included in the sampling of cycle 2. Since the WLF continuously harvested these remaining fish (Figure 9), it is likely that in month four they were all removed, leading to a further decrease of the average fish weight. In month five, the initial sampling method was resumed.

To summarise, although the individual biomass gain of the fish in cycle 2 was generally lower in comparison to cycle 1, the total biomass gain may even be higher, due to more than one generation of fish in the pond.

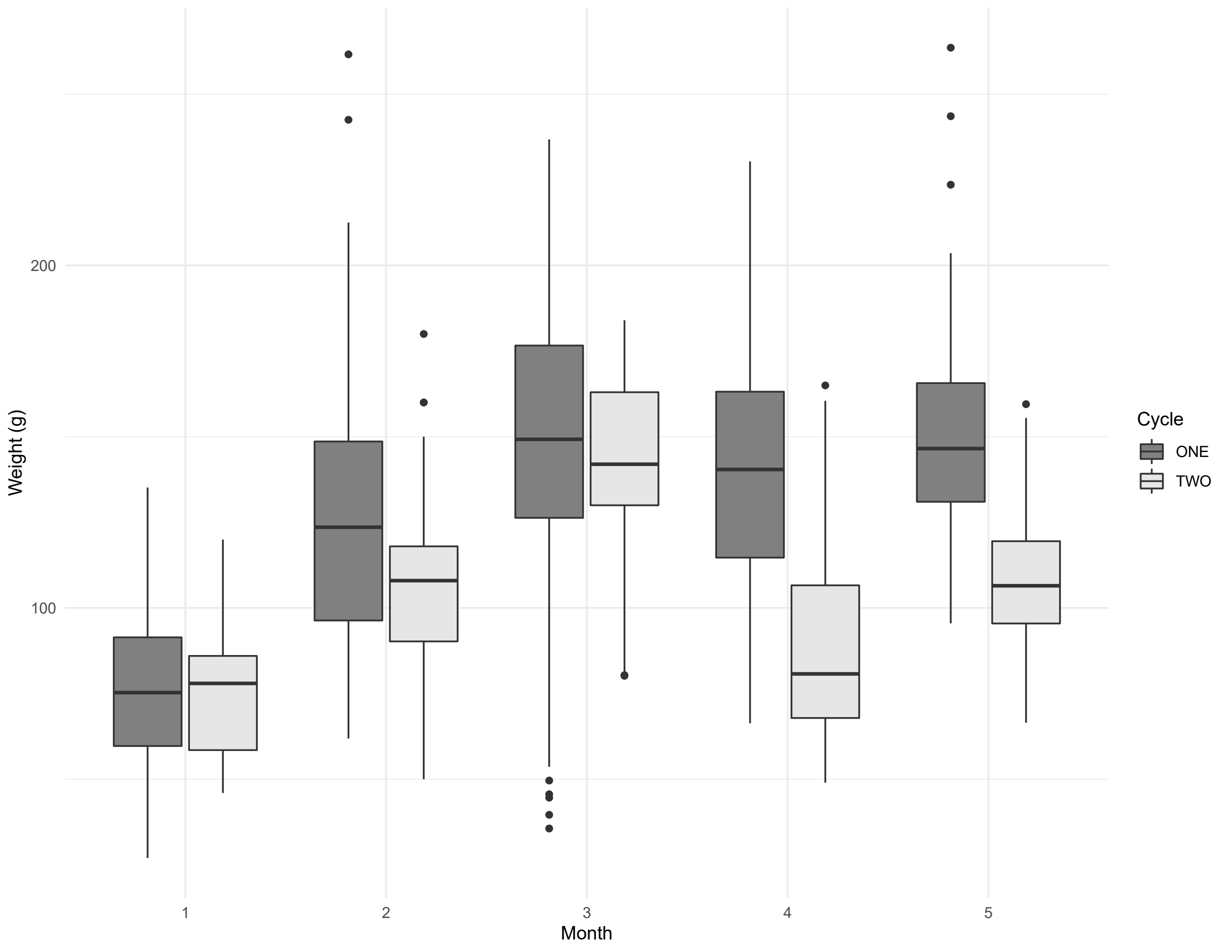

Figure 5 Average growth of fish in cycle 1 and cycle 2 of all 8 WLFs in the course of the first 5 months, each box is based on 80 data points (average weight of 5 fish result in 1 data point)

3.1.2 Feed conversion ratio

The calculated biological FCR of all WLFs has increased from an average of 2.32 (excluding WLF 8, because all her fish died early on) in cycle 1 to an average of 3.93 in cycle 2. Figure 6 shows the differences in the FCR of each WLF and cycle. The only WLF that shows an increase of the FCR from cycle 1 to cycle 2 is WLF 10. However, the resulting FCR is inaccurate in at least five out of eight WLF. The FCR was calculated for all WLFs based on the supplied fish for cycle 2. WLF 1, WLF 2, WLF 3, WLF 4 and WLF 10 had a significant number of remaining fish from cycle 1 in the pond, which was estimated to be in the range of 50 to 170 kg. Furthermore, the fish from cycle 1 had reproduced themselves. Since the biomass in the pond was not assessed at the beginning of cycle 2, the data base is not accurate enough in order to calculate the effective FCR. WLF 7, WLF 8 and WLF 9 on the other hand had emptied their pond. Thus, their calculated FCR is the most representative.

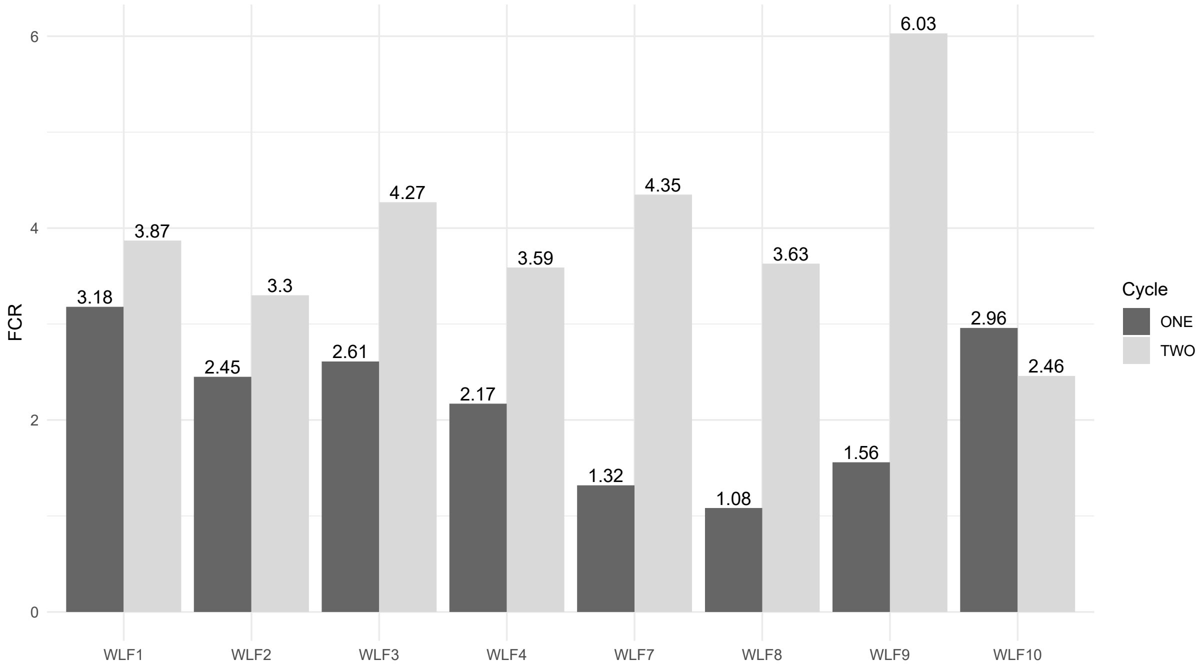

Figure 6 Feed conversion ratio of cycle 1 and cycle 2 of all WLFs

3.1.3 Mortality rate

Cycle 1 was characterized by a very high mortality rate for most WLFs. However, in cycle 2 the mortality rate decreased drastically. Out of a total of 9840 stocked fish in cycle 1, 3184 fish died, which corresponds to a mortality rate of 32.36 %. In cycle 2, a total of 8900 fish were stocked of which 241 fish died, which results in a mortality rate of 2.7 %. Thus, when comparing the mortality of cycle 1 to cycle 2, a reduction of 29.66 % occurred. Figure 7 illustrates mortality of fish in kg of each WLF for each cycle.

Oxygen depletion caused by overfeeding can be attributed as the main factor for the high mortality rate in cycle 1. The WLF were inexperienced as they were operating their pond for the first time, resulting in partly inaccurate management. In cycle 2, however, the WLFs were more cautious, especially with regard to feed management, which reflects their higher level of experience. In addition, the SOS certainly contributed to the high survivability of fish in cycle 2 by increasing oxygen levels in pond.

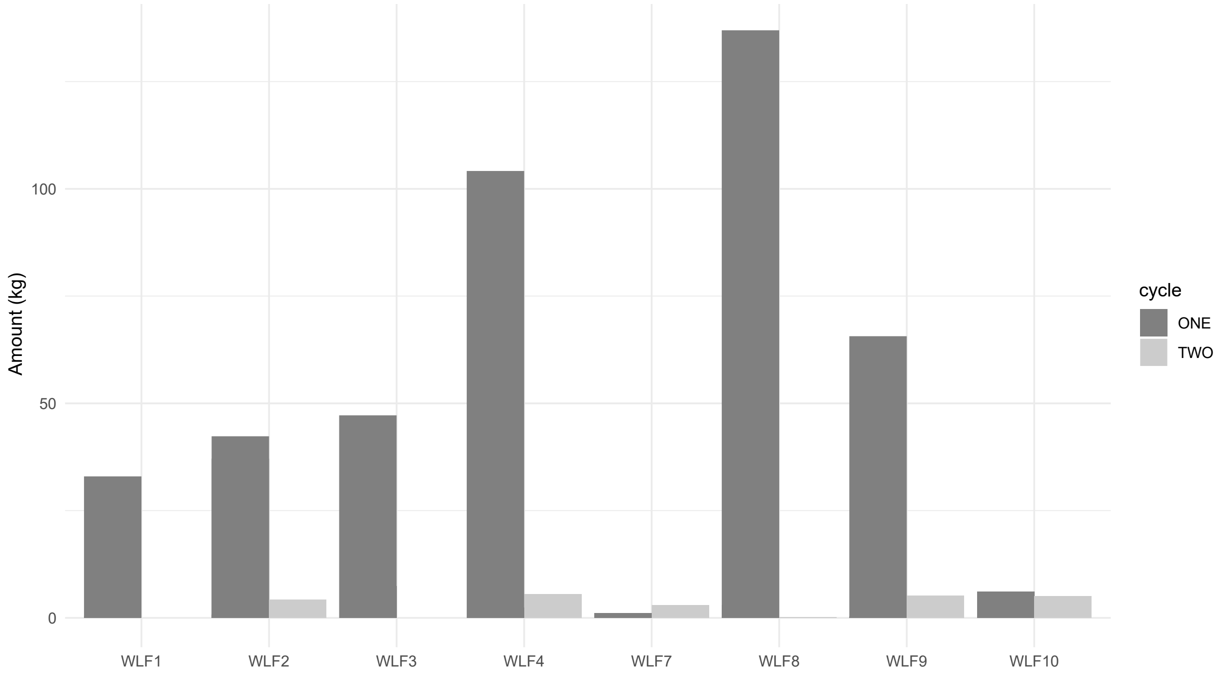

Figure 7 Mortality of fish in kg of each WLF in cycle 1 and cycle 2

3.1.4 Fish production

In cycle 1, the WLF started to harvest substantial amounts of fish as of month four, visible in Figure 8. In cycle 2, the main harvests only started as of month six, which is displayed in Figure 9. This can be attributed to the reduced fish size of cycle 2, thus, the WLF were waiting for the fish to reach an adequate size. However, regular harvests of remaining fish from cycle 1 were taking place throughout the first months of cycle 2, since the WLF did not completely harvest the fish in their pond in cycle 1. During the period of data collection, a total of 988 kg of fish were harvested in cycle 1, whereby 36 % were consumed by the WLF and their families and 64 % were sold. In cycle 2, a total of 611 kg of fish were harvested, whereby 52 % were consumed and 48 % sold.

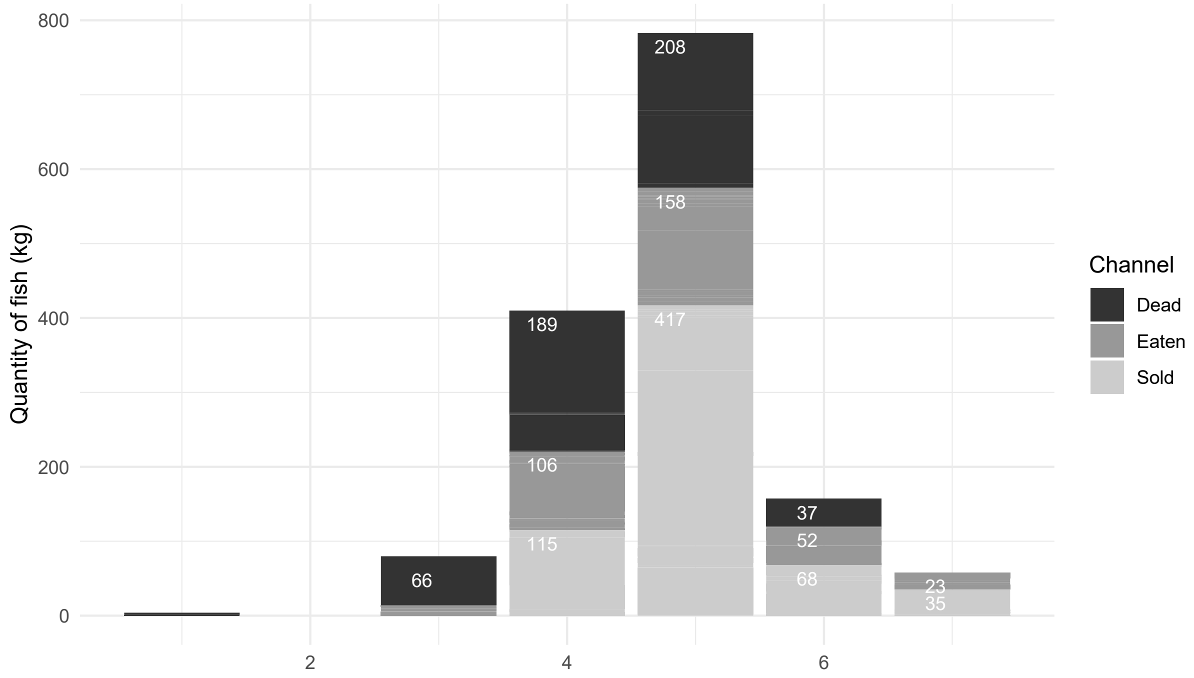

Figure 8 Total harvest and dead fish in kg of all WLFs per month in cycle 1

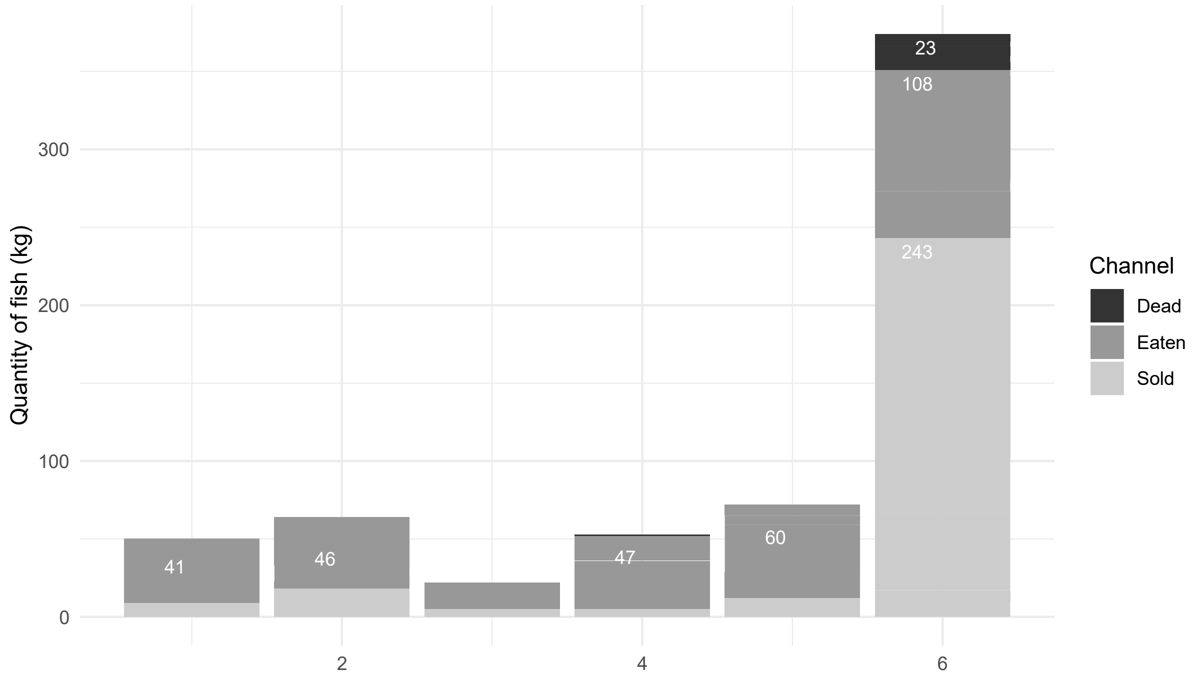

Figure 9: Total harvest and dead fish in kg of all WLFs per month in cycle 2

3.2 Agricultural production

Since the first baseline survey in 2020 before cycle 1, the WLFs have significantly extended their agricultural production and expanded crop diversity. For most WLFs, the pond was also frequently used to irrigate the agricultural crops in cycle 2, which is displayed in **Error! Reference source not found.**. Figure 10 illustrates the increase in total agricultural production, which rose from 671 kg before cycle 1 to 1442 kg before cycle 2. This corresponds to a growth of 115%. When shifting into cycle 2, production has decreased. The decrease can be attributed to the fact that cycle 2 was taking place during dry season.

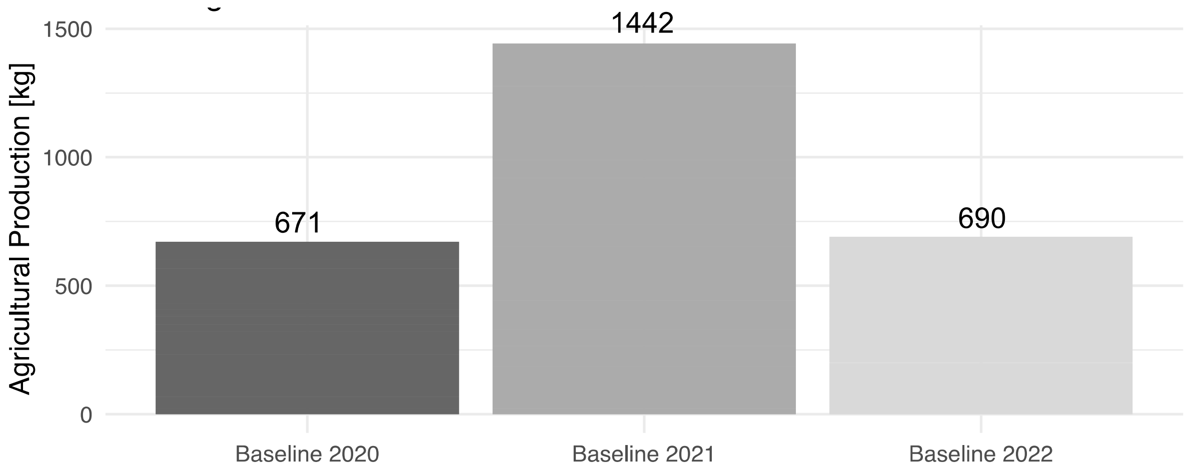

Figure 10 Total agricultural production before cycle 1 (baseline 2020), before cycle 2 (baseline 2021) and during cycle 2 (baseline 2022)

Table 2 Use of pond to irrigate the agricultural crops during cycle 2 (baseline 2022)

	WLF 1	WLF 2	WLF 3	WLF 4	WLF 7	WLF 8	WLF 9	WLF 10
Average use of pond for irrigation (times/week)	0.6	1.1	2.55	0	0	1.65	2.35	0.8

Crop diversity has also significantly increased and is displayed in
Figure 11 Number of agricultural crops produced by before cycle 1 (baseline 2020), before cycle 2 (baseline 2021) and during cycle 2 (baseline 2022). Crops produced on average per WLF rose from 2.625 before cycle 1 (baseline 2020) to 9.75 before cycle 2 (baseline 2021). During cycle 2, crops produced on average per WLF reached 3.75. However, production quantities between the WLF vary substantially, which is illustrated in **Error! Reference source not found.**. Six out of eight WLFs have increased their production quantities in the course of cycle 1 to cycle 2. WLF 7 and WLF 3 however did not produce any agricultural crops during cycle 2. A possible explanation is that WLF 7 started to work in a factory, which may have prevented her from growing crops. Furthermore, WLF 3 has been facing family issues since the beginning of cycle 2, which have prevented her from contributing to the agricultural production. Nonetheless, crops are still being produced around the pond, although not managed by her anymore.

The quantities of the produced crops are displayed in Appendix B. The crops of which the largest quantities were produced are Chaya Spinach Tree, Morning Glory and Lemon Grass

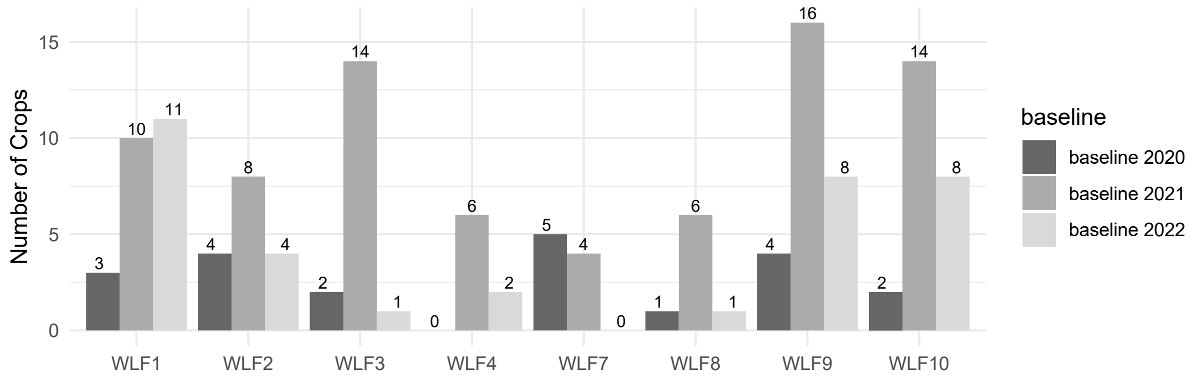

Figure 11 Number of agricultural crops produced by before cycle 1 (baseline 2020), before cycle 2 (baseline 2021) and during cycle 2 (baseline 2022)

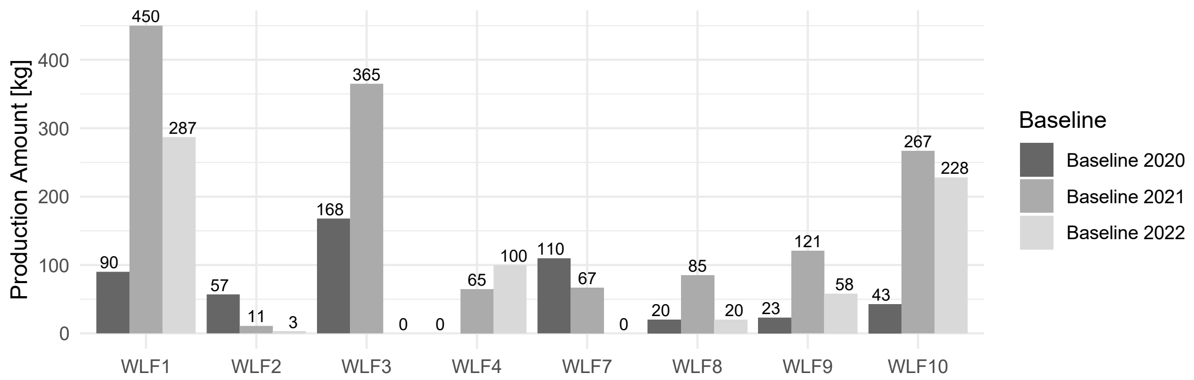

Figure 12 Agricultural production of WLF in kg before cycle 1 (baseline 2020), before cycle 2 (baseline 2021) and during cycle 2 (baseline 2022)

3.3 Economic viability of WLF

3.3.1 No payback of seed fund (CapEx)

On average the WLFs are able to cover their operational cost and generate profit, which is displayed in Table 3. Solely based on the aquaculture production, the average annual profits amount to 147.1 $. Adding the income of the agricultural production, the annual profit increases to 267.3 $. An annual profit of 267.3 $ corresponds to a monthly wage of 22.3 $. The recommended workload to operate the pond is 2 hours per day (Scott, 2022a), which amounts to 60 hours of work per month. Thus, the hourly wage is 0.37 $. However, a further increase could be attained by reducing operational costs, which could be done by supplementing a share of the commercial feed. Some WLFs have already demonstrated the potential by producing their own feed with on-farm products like Rice Bran, Moringa and Chaya Spinach Tree. If 30% of the commercial feed was replaced by on-farm produced supplement feed, operational cost could be reduced, resulting in an annual profit of 364.5 $, which corresponds to 30.38 $ per month and is illustrated in Table 3.

3.3.2 With payback of seed fund (CapEx)

The payback period for the seed fund of 1959.7 $ (without interest rate) are displayed in Table 4. If the operational income only consists of the fish sold, the payback period would amount to 13.32 years. Including agricultural production, the payback period decreases to 7.33 years. Furthermore, if the expenses for commercial feed decreases by 30 %, the payback period amounts to only 5.38 years. Yet, assuming that the seed fund has a monthly interest rate of 1 %, which is in the range of Cambodia's interest rates (World Bank, 2021a), the payback period would increase significantly to 8.675 years. Thus, the farmer would start to generate profit after 8.675 years.

Table 3 Average profits of all WLFs per year and cycle without investment cost (CapEx).

Aquaculture	**$**	**Aquaculture /Agriculture**	**$**	**Aquaculture/Agriculture/ Supplement feed**	**$**
OpEx	413	**OpEx**	413	**OpEx**	315.8
Income aquaculture	560.1	**Income aquaculture**	560.1	**Income aquaculture**	560.1
		Income agriculture	120.2	**Income agriculture**	120.2
Annual profit	147.1	**Annual profit**	267.3	**Annual profit**	364.5
Monthly profit	12.25	**Monthly profit**	22.3	**Monthly profit**	30.38
Hourly profit	0.2	**Hourly profit**	0.37	**Hourly profit**	0.5

Table 4 Average payback time of all WLFs of seed fund (CapEx).

Aquaculture	**$**	**Aquaculture /Agriculture**	**$**	**Aquaculture/Agriculture/ Supplement feed**	**$**
CapEx	1959.7	**CapEx**	1959.7	**CapEx**	1959.7
OpEx	413	**OpEx**	413	**OpEx**	315.8
Income aquaculture	560.1	**Income aquaculture**	560.1	**Income aquaculture**	560.1
		Income agriculture	120.2	**Income agriculture**	120.2
Annual profit	147.1	**Annual profit**	267.3	**Annual profit**	364.5
	years		years		years
Payback period	13.32	**Payback period**	7.33	**Payback period**	5.38

3.3.3 Variability among farmers

The economic viability varies greatly between the farmers and is illustrated in Table 5. WLF 1 generates the highest income while WLF 4 generates the lowest. The differences are predominantly based on the agricultural production. This shows that it is beneficial for the WLF to increase the agricultural production, as it greatly influences the profits and decreases the payback period.

Table 5 Profits through aquaculture and agricultural production of WLF 1 and WLF 7

WLF 1		WLF 4	
	$		**$**
OpEx	413	**OpEx**	413
Income aquaculture	623.6	**Income aquaculture**	430.8
Income agriculture	343.8	**Income agriculture**	54.2
Annual profit	554.4	**Annual profit**	72
Monthly profit	46.2	**Monthly profit**	6
Hourly profit	0.77	**Hourly profit**	0.1
	years		years
Payback period	3.53	**Payback period**	27.23

3.4 Success assessment

This section provides information about the success of the project in social terms. Figure 13 illustrates that all of the WLFs recommend the project/small-scale aquaculture to other women. Furthermore, all of them are willing to support fellow Woman Leader Farmers to some degree, which underlines the potential of extending the project by recruiting further WLFs. While 75% answered with a clear "yes" in regard to supporting fellow farmers, 25% of the WLFs were not yet completely certain about assisting other farmers.

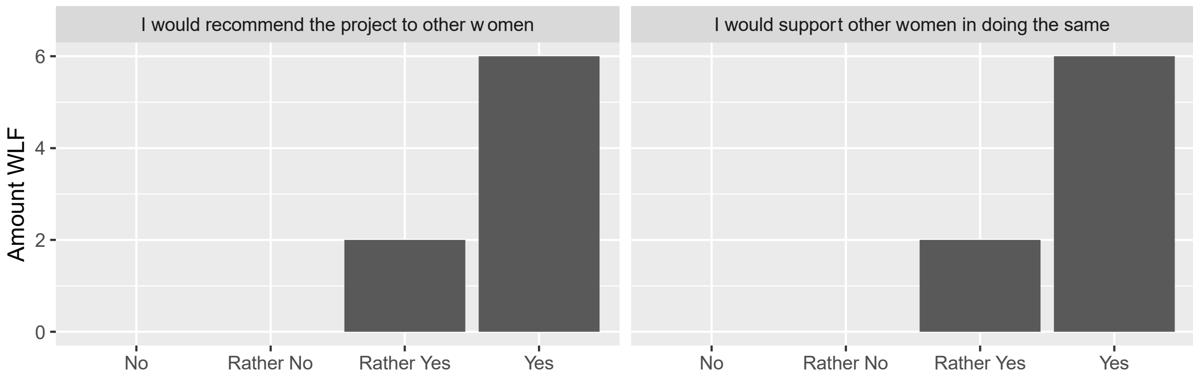

Figure 13 Potential of expanding the project according to WLFs view on small-scale aquaculture

At the beginning of cycle 1 in baseline 2020, some of the WLFs were facing challenges in providing sufficient amount of food to their families due to a lack of financial resources. Figure 14shows that the consumption of fish has increased in most WLFs, which may have contributed to the general consent that the pond has made a positive impact in their lives. This is exemplified in Figure 15. Moreover, the WLFs are mostly positive about their future.

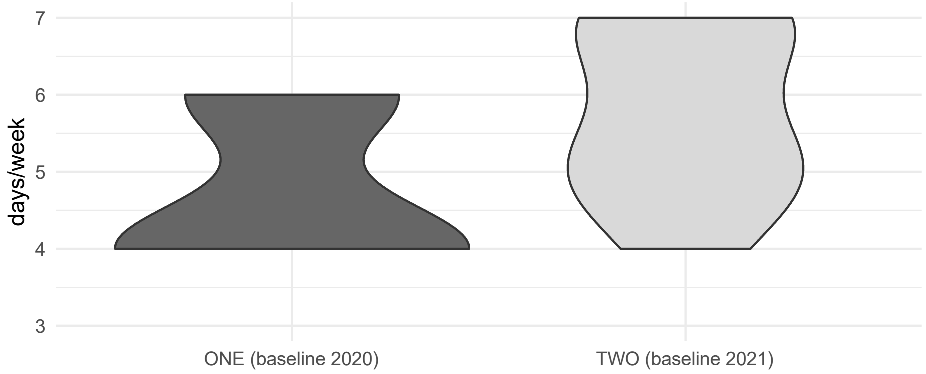

Figure 14 Total consumption of fish in days per week of all WLFs before cycle 1 (without pond) and before cycle 2 (with pond).

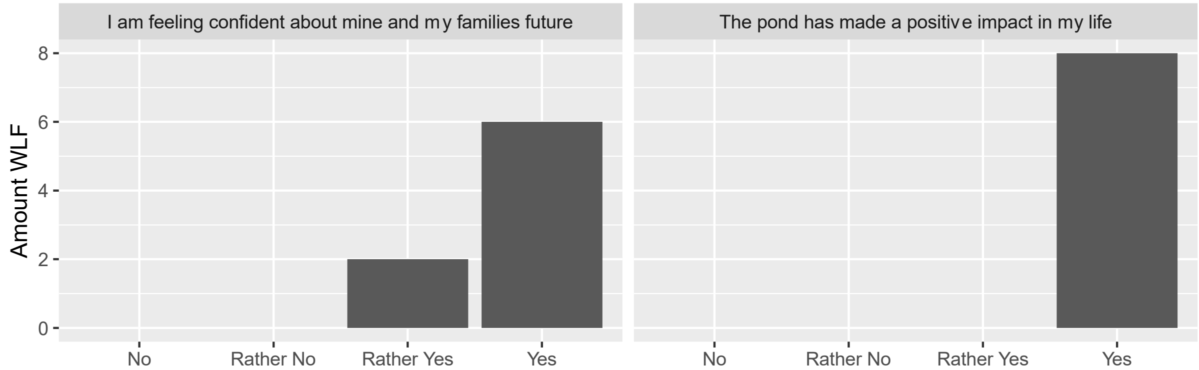

Figure 15 Impact of ponds on WLF

According to Figure 16 all participants seek to expand their business activities. Five WLFs have already installed additional ponds on their land and seven out of eight WLFs will certainly further expand their aquaculture production. Moreover, 50 % of the WLFs are committed to expanding their agricultural production. The lack of water during the dry season was the main reason for 75 % of the WLFs that prevented them from extending their agricultural production prior to cycle 1. Besides the increase of the agricultural crop production that occurred in the course of cycle 2, the secured availability of water on the farm led to other positive effects. WLF 4 for example has started to farm ducks, which are partly fed with water hyacinths that are cultivated on the pond surface.

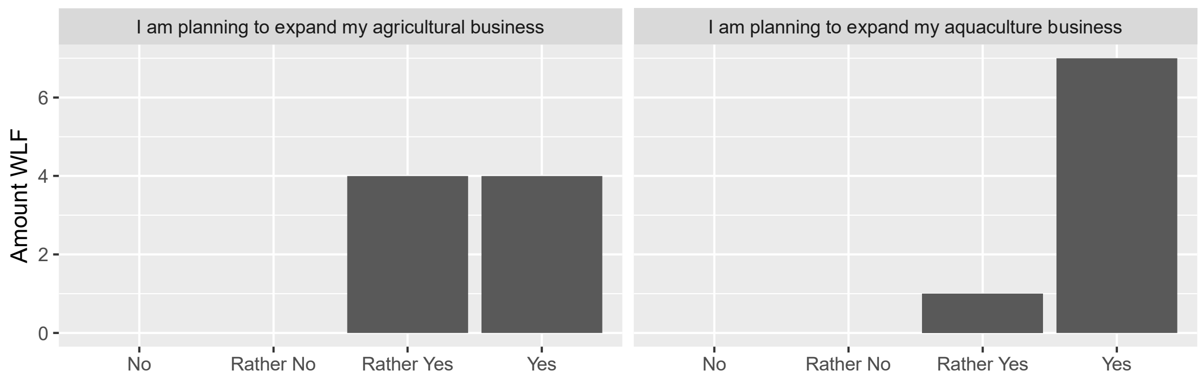

Figure 16 Business expansion plans of all WLFs

All WLFs stated that they wish to receive more support regarding aquaculture production, while about 50 % of the WLFs sometimes feel overburdened by the task of learning about aquaculture. This is illustrated in Figure 17 and may be related to the high general workload of women in Cambodia. Three of the WLFs who stated to feel overburdened, are either working in a factory full time or have been struggling with health problems, while one WLF is a mother of an infant.

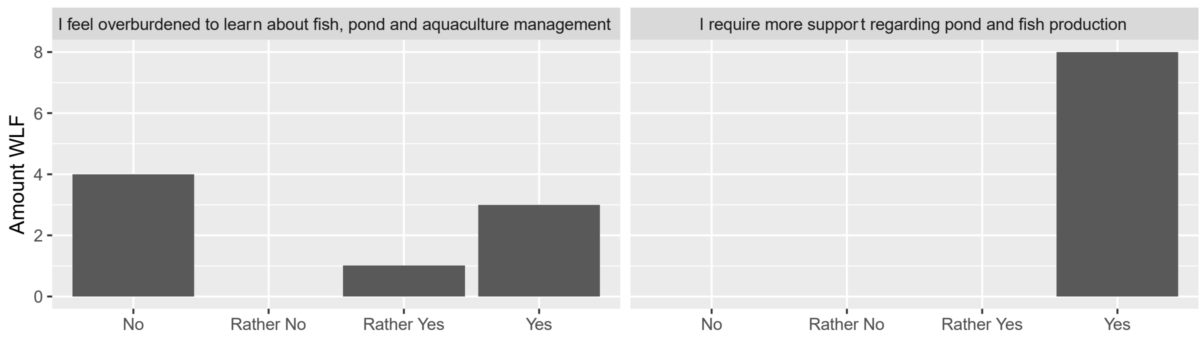

Figure 17 Personal opinion of WLF on learning about fish farming and project support

3.5 Technical aspects of the Sun-Oxygen-System

Implementing the SOS in the ponds of the WLF in cycle 2 was the first ever practical application of this technology beside the prior trial at SGC. For most part the SOSs were functioning well, and the implementation was a success. However, seven out of eight WLFs required professional assistance in order to repair their system. The interventions and repairs that were undertaken during cycle 2 are displayed in Appendix C. Most defects could be attributed to one major deficiency, which was a regular breakdown of the pumps (Model IPX8). Since the pumps could not be repaired, they had to be replaced. Yet, with a price of 64 $ per pump, the cost of exchange is significant, especially for the WLFs. Considering that the pumps of the previous SOS models have been running since 2020 without comparable defects, the motors of the SOSs at the WLFs were exchanged back to the previous model (Jebao RW-20). Because the latter are 12 $ more expensive, the overall investment cost for the SOS increases.

Nonetheless, when taking into account the material and labour cost of exchanging the pump once (Model IPX8), the set-up with the previous pump (Jebao RW-20) results to be more economical.

4 Discussion

4.1 Aquaculture production

At the start of the project when fish were stocked for cycle 1, the pond was empty. However, at the beginning of cycle 2 not all fish had been harvested. This led to natural reproduction of the tilapia population in the pond. According to Rakocy (2022) ponds with mixed-sexed tilapia populations can consist up to 70% of offspring at the time of harvest. Based on the extracted fish of the seine net sampling it is assumed that these other generations accounted for approximately 20 % of the total biomass in the pond.

4.1.1 Fish size and weight gain

According to the results, the fish size per month was lower in cycle 2. While it is likely, that results were negatively affected by offspring that was included into the samplings, it is realistic that the fish size was generally lower than in cycle 1. This can be attributed to the concurrence due to the uncontrolled reproduction. The reproduction can lead to overpopulation, which can drastically decrease the growth of fish (Bhujel & Suresh, 2000). Figure 18 shows the size distribution of the fish in the pond of WLF 7.

Figure 18 Size distribution of fish in the pond at WLF 7

4.1.2 Feed conversion ratio

Although results indicate an increase in the FCR from cycle 1 to cycle 2, many factors have influenced the parameter negatively. The unknown effective biomass due to the natural reproduction is one of these factors. Furthermore, it was observed that in some cases, the WLF did not feed their fish according to instructions. Since the WLF only had one size of pelleted feed available, which was too large for the fingerling of 20 g of weight, they were advised to crush the pellets in the beginning of the cycle. However, not all WLFs followed the instruction. In result, the beginning of the cycle, when the new batch of fingerling was stocked, was characterized by a lower feed intake, because the remaining fish from cycle 1 were easily consuming the 5 mm pelleted feed in comparison to the fingerling, thus directly competing with the smaller fish. Another factor that could have influenced the weaker growth performance in cycle 2 is the different feed brand with a lower protein content. Moreover, did the women financially partake in the feed cost in cycle 2, whereas in the cycle 1 they were supplied with feed free of cost. This could also have influenced the way they managed the feed. WLF 3, WLF 4, WLF 7, WLF 8 and WLF 9 have installed additional ponds on their land in the course of the project. It is plausible to assume that they did not use the feed exclusively for the pond within the project, but also supplied their additional pond with the same feed or even fed their livestock with it.

Nonetheless, on the basis that WLF 7, WLF 8 and WLF 9 had no fish from cycle 1 remaining in their pond, it could be assumed that their values are representative. However, the FCR of WLF 9 amounts to 6.03, which is unrealistic considering that the fish were fed with commercial feed. Furthermore, tilapia fed solely with agricultural biproducts were still reported to have an FCR of 2.47 (Aanyu et al., 2017). Thus, other factors have influenced the outcome. It was observed that her fish were fed with raw leaves of the Chaya Spinach Tree. While this plant has high nutritional values and can be consumed safely after it is cooked, the raw consumption of the plant has toxic effects (Gonzalez-Laredo et al., 2003). Moreover, the fish of WLF 9 were much smaller in size than fish of other WLF, which could be an effect of the toxicity of the plant.

4.2 Efficiency of the Sun-Oxygen-System

The aim of the SOS was to increase oxygen levels in the fishpond and through this the growth performance. Furthermore, it should also improve the feed conversion ratio as well as the fish survivability. However, based on trial set-up and the resulting data, it is not possible to clearly identify to which degree the SOS contributed to better operational performance. However, although better survival in cycle 2 could be attributed to the improved management capabilities of the WLF, the SOS may also have contributed to the drastic amelioration. Mortality was reduced by an average of 367 fish per WLF in comparison to cycle 1. This corresponds to a value of 147.15 $ of fish, if sold at 200 g. Assuming that half of the improved survivability is due to the SOS, the cost of 253.5 $ would be paid off after 3.4 cycles, just by reducing mortality. Yet, the SOS was requiring regular repairs during the trial, which shows that there is still room to further improve the system. Thus, in order to conclusively state, if the investment in an SOS is worth for the WLF, further research needs to be conducted.

4.3 Economic viability

The analysis of the economic viability has revealed that all WLFs are able to generate earnings, while covering their operational cost, visible in Appendix E. WLF 1, who has achieved the highest income, resulted to have a monthly profit of 46.2 $. At 60 hours of work per month, this corresponds to an hourly wage of 0.77 $, which lies just under the hourly wage of a garment factory worker at 0.83 $, where the monthly minimum wage is 180 $ (Cassinerio, 2022), at an average workload of 216 hours per month (ILO, 2018). The WLF with the lowest income only generated 0.10 $ of profit per hour. Low incomes of the WLFs could be attributed to low agricultural production. This shows that increasing agricultural production around the pond directly increases profitability. Moreover, carrying out a number of different activities, can lead to a better economic stability based on a more continuous liquidity (Popp et al., 2019). Five out of eight WLF have additionally produced livestock. However, income resulting from livestock was not included in the economic analysis.

It can be stated that WLFs who generated the lowest incomes were more active in livestock production than agricultural production. However, due to the difficulty of assessing the direct impact of the pond to livestock production, this income category was not included. Yet, it was observed that the fishpond was supplying feed like water hyacinths to ducks. Using the pond to produce livestock feed was already observed in fishpond based farms in Vietnam (Zijpp et al., 2007). Thus, if the incomes of livestock had been included in the economic analysis, their profits would have been higher.

Based on the observed natural reproduction of the fish and thus the increased biomass, it is likely that the effective incomes through aquaculture production may be higher. Furthermore, fingerlings would only need to be purchased at the start of the production, since they naturally reproduce, which would reduce operational costs (OpEx). Based on the observations when conducting the research, it could be assumed that the quantity of fish lies 20 % higher due to offspring. Including these additional 20 % results in a profitability increase of 12 % to almost 120 %. Thus, hourly wage of the WLF with the most income would increase from 0.77 $ to 0.87 $ while the WLF with the lowest hourly wage at 0.10 $ would earn 0.30 $. However, naturally uncontrolled reproduction can also be an issue. It can lead to large size disparities among the harvested fish as well as to an increased competition for food and stunting of the original stock (Rakocy, 2022). Consequently, it is important to accurately manage the fish stock. This can be done by periodically harvesting fingerlings (Fortes, 2005), which could be sold to other aquaculture farmers in order to generate further income. To avoid a decreased growth due to the uncontrolled reproduction, it is recommended to regularly remove all fish, restock the pond with uniform sized individuals, and sell excess fish (Fortes, 2005). In case farmers decide not to harvest and sell fingerlings, thus managing their pond accordingly, stocking sea bass, a carnivorous fish, with a ratio of 1:20 (predator-prey) could be an approach in controlling the population size (Fortes, 2005).

The thesis could prove that granting seed money to build a pond can help increase women's economical participation and ensure an adequate supply of animal protein for the family. An average of 120 kg of fish per year could be consumed by the WLFs while the operational costs are still covered. Based on the success assessment, it is expected that future incomes will increase, since all WLFs stated that they plan to expand their aquaculture and agricultural production.

If the seed money (CapEx) was to be repaid, the payback period without reduction of commercial feed amounts to 7.33 years with a rate of return at 13.64 %. However, adding Cambodian interest rates to the seed money, the payback period increases to 17.68 years, which is extremely high, considering that opportunity costs are not included in the analysis. Nonetheless, there is potential to reduce the investment cost (CapEx). Due to sandy soils in the region, the ponds were constructed with pond liners in order to ensure water retention. In the course of the trial a number of WLFs have independently added a second pond onto their land. However, the latter were simply constructed earthen ponds. Yet, they were always containing water. Therefore, future ponds could be constructed without a pond liner, which would reduce investment cost (CapEx) by half and reduce the payback period to 3.9 years while the return of investment increases to 25.39 %.

Sustainably engaging women in aquaculture requires an educational program. While the WLFs were educated through workshops, future WLFs could be educated with online courses. Furthermore, the WLFs showed that constructing an earthen pond does not necessarily require a financial investment, as they had their ponds constructed at no cost in exchange for their soil. Thus, it could be sufficient to provide knowledge through online courses and grant seed money only for the initial batch of fingerlings and feed for the first cycle. The cost would amount to 413 $ and break-even would be achieved after only 0.61 years. Additionally, the WLFs stated that they are open to assist future WLFs. Consequently, a network could be built where experienced WLFs could support fellow WLFs with their knowledge.

Promoting aquaculture through social media, providing educational courses and building a network of women fish farmers could not only increase women's economic participation and contribute to better food security in the family but also help prevent migration in order to find employment. It is reported that an increasing number of young girls are leaving school in order to find work in the garment factory to support their family (Creamer et al., 2017). A pond close to the household provides opportunities that go beyond farming fish (Zijpp et al., 2007) and could offer young women new perspectives.

4.4 Reducing malnutrition

Bhujel et al., (2008) stated in his research that engaging women in aquaculture improved the protein intake of the family. The findings in this thesis underline this statement, since the weekly consumption of fish generally increased.

Moreover, did the agricultural production significantly expand in the course of the trial and it could be identified that most WLFs used their pond to irrigate their crops on a weekly basis. This indicates that having access to a pond and thus, sufficient amounts of water, also increases the general availability of food due to a greater mass of agricultural production. However, in order to verify the direct impact of the pond in regard to the agricultural production, it would have been beneficial to include the quantity of water used per irrigation.

Furthermore, does the pond provide valuable nutrients in form of sludge that accumulates at the bottom of the pond. Research has shown that applying the sludge onto agricultural crops leads to significantly higher yields (Shamsul et al., 2007). Therefore, it is an additional mean that could contribute to reducing malnutrition.

Additionally, a number of other species were found to have naturally settled in the ponds. These include Climbing Purch, Gurami, Catfish, Pangasius and Snails. The latter settled on the dyke slopes of the pond and were regularly collected for consumption by the WLFs. Having additional species contributes to a diversification of food supply.

4.5 Accuracy of data

In the course of the thesis, it became clear that the data base was not comprehensive enough to answer all study objectives. Based on different cycle set-ups and the resulting data, it is not possible to conclude whether the SOS leads to an improved fish growth and FCR. The thesis would have benefited, if the pond had been fully emptied prior to stocking the fish for cycle 2. However, the finding that the fish naturally reproduce very well under given circumstances, could only be made, because the pond was not fully emptied.

Furthermore, pretesting the surveys was only done with two persons and preliminary conducted data was not evaluated. This could have led to false responses, since questions may have been misinterpreted. For further research, it is be valuable to pre-test the survey as well as the data within a larger group that is not related to the trial, before its final application.

The language barrier between the survey developer, the survey conductor, and the survey participants may also have influenced the data.

5 Conclusion

Engaging women in small-scale aquaculture has shown to provide both economic and social benefits. The Women Leader Farmers have successfully operated their ponds and carried out two rearing cycles with tilapia of which a significant share of fish was sold. The analysis of the economic viability of the eight farms has revealed that operational costs could be covered, and profits were generated. A determinant factor in attaining higher profits was the integration of agricultural crop production. If the capital investment was to be paid off, break-even can be attained after 7.3 years. A significant reduction of the capital investment and thus a shorter payback period could be achieved by building ponds without liner.

Yet, the effects of the Sun-Oxygen-System on the ponds performance in the second rearing cycle could not clearly be determined. Although mortality was significantly reduced, which could be attributed to the implementation of the SOS, data on fish growth and FCR do not allow a final conclusion. It is recommended that further research should be conducted before the system is widely promoted for its benefits.

The social success assessment has shown that the farmers recognized the positive effects that a pond can provide. They have regularly used their pond in order to irrigate their agricultural crops. Some farmers additionally cultivated water hyacinths on the ponds surface to feed their livestock. Furthermore, the consumption of fish has increased by one day per week, which is an important attribute in light of Cambodia's stagnating fish catches.

Finally, results underline that granting a seed fund for women to build their own aquaculture business does have various positive impacts. However, the amount of seed funding does not necessarily need to cover the total capital investment costs of a pond. Some farmers have independently constructed a second pond on their land. Thus, granting smaller amounts of seed funding in order to buy a first batch of fingerlings and feed while providing educational material in form of workshops or online classes on aquaculture can already alleviate women's economic participation and reduce malnutrition.

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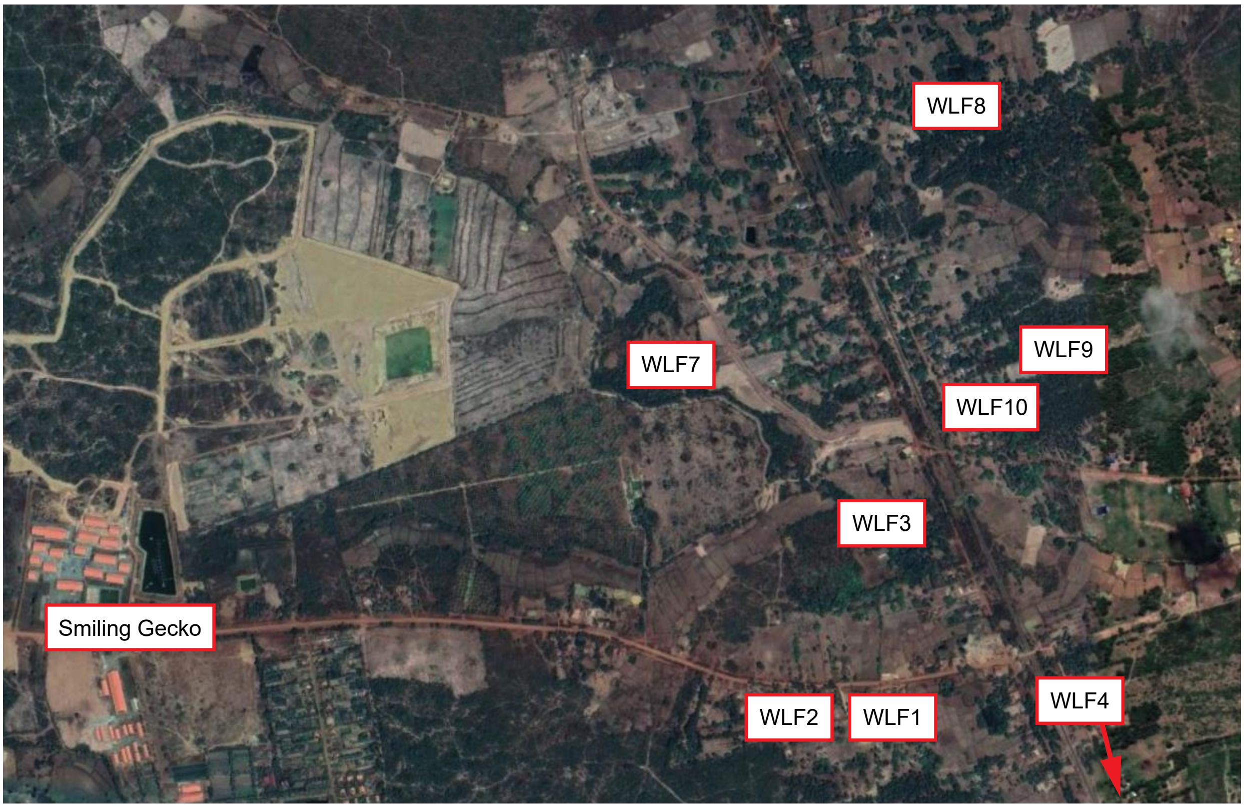
Appendix

Appendix A

Detailed overview of woman leader farmers (WLF)

The woman leader farmers are all located near Smiling Gecko and can be reached from there with a motorised vehicle in 5 to 15 minutes. WLF 4 is the furthest away. Table 1-8 contain basic information to each WLF as well as an image of their pond.



WLF 1

Name	Sory Rort
Date of birth	19.01.1994
Years of schooling	7
Family members	3

WLF 2

Name	Yin Kaychin
Date of birth	01.01.2000
Years of schooling	6
Family members	3

WLF 3

Name	Sang Da
Date of birth	15.07.1983
Years of schooling	3
Family members	4

WLF 4

Name	Yang On
Date of birth	07.06.1977
Years of schooling	2
Family members	4

WLF 7

Name	Peou Maly
Date of birth	10.01.1992
Years of schooling	4
Family members	5

WLF 8

Name	Sann Mai
Date of birth	13.01.1975
Years of schooling	6
Family members	2

WLF 9

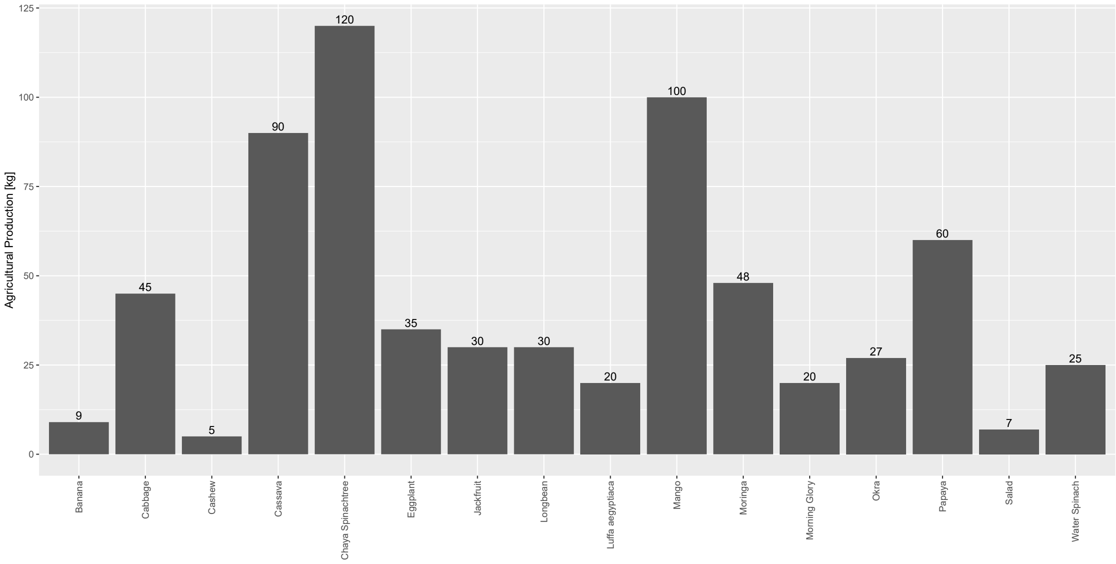
Name	Sun Savath
Date of birth	11.04.1980
Years of schooling	8
Family members	3

WLF 10

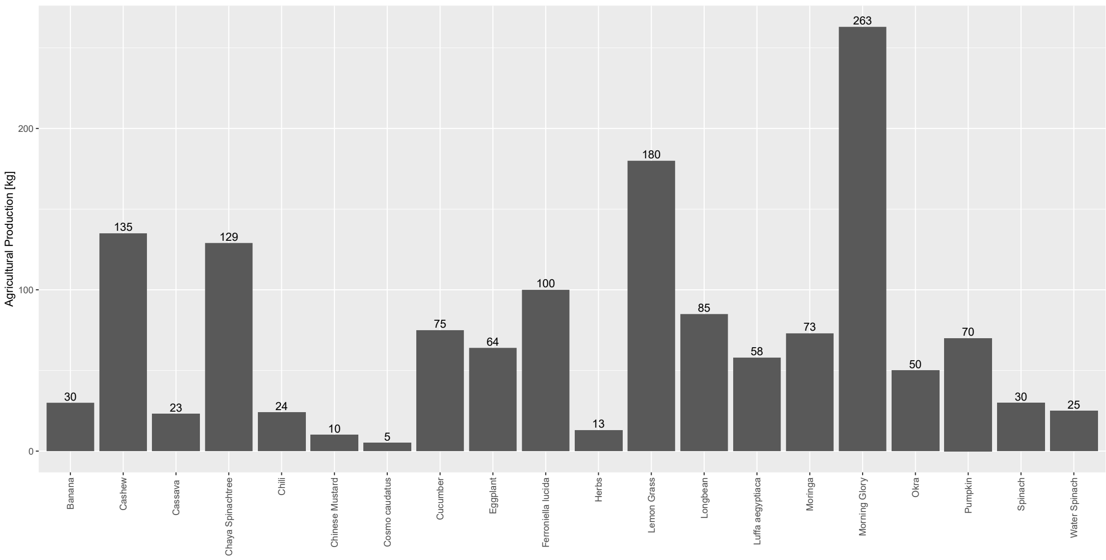
Name	Duk Nam
Date of birth	01.02.1964
Years of schooling	2
Family members	7

Appendix B

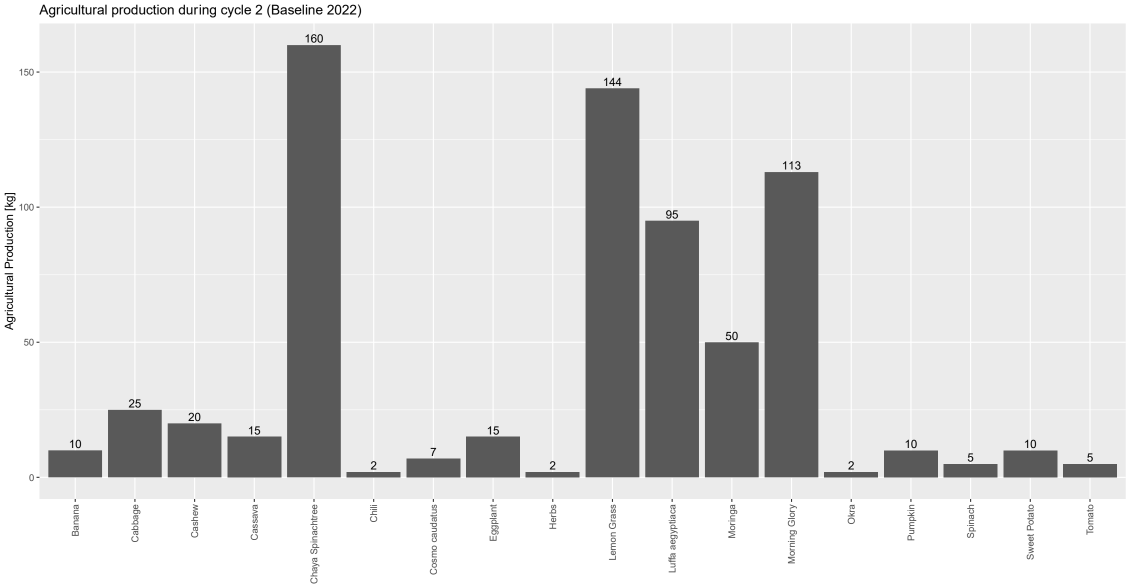
Agricultural production before cycle 1 (Baseline 2020)



Agricultural production before cycle 2 (Baseline 2021)



Agricultural production during cycle 2 (Baseline 2022)



Appendix C

SOS Problem Record

Date	1	2	3	4	7	8	9	10	Problem	Cause
13.09.2021					X				Increased speed of pump	Unknown
17.09.2021					X				Pump not running, mounting bracket broke	Mounting bracket from plexiglass too fragile
17.09.2021		X							Pump not running, propeller blade from pump broke	Unknown
17.09.2021							X		Pump not running, detached from mounting bracket	Screws became loose
25.10.2021							X		Pump not running, electronics damaged	Condense water in the box triggered short circuit
23.11.2021		X							Irregular speed of pump	Unknown
11.01.2021					X				Irregular speed of pump	Ball-bearings of pump broke
11.01.2021								X	Pump not running, propeller blade from pump broke	Unknown
24.01.2022				X					Pump not running	Ball-bearings of pump broke
08.02.2022							X		Pump not running	Ball-bearings of pump broke
28.02.2022						X			Pump not running	Ball-bearings of pump broke

Appendix D

Technical aspects of the Sun-Oxygen-System

The implementation of the SOS in cycle 2 has revealed a number of deficiencies. The SOS had to be repaired on a regular basis in 75 % of all WLFs. The deficiencies helped to identify measures for improvements.

Foremost, the motor that was used as a pump in the SOS did not withstand the excessive operating time and the environmental conditions. The plastic of the propeller broke without major impact multiple time. The most fundamental deficiency though, was the fragility of the motor itself. It contains rolling bearings, which over time got blocked and broke.

The former pump “Jebao RW-20”, was tested over a longer period of time in the ponds at Smiling Gecko and did not require any reparation or exchanges (Konrad, 2021). It was designed especially for aquariums, thus it fit the purpose. But based on the inefficiency regarding its power utilisation, it was exchanged by a pump of the model “IPX8”, which was capable of using the supplied power much more efficiently (Vuillemin, 2021). However, the testing of the pump was done in a bathtub thus it did not represent the reality. During its practical application it became clear that the motor does not withstand the conditions of running for a long period of time and especially remaining in the water 24/7. Since a regular exchange of the motor would be extremely cost intensive, it is recommended to exchange the motor back to the model “Jebao RW-20” that was successfully tested in the first version.

Furthermore, it is questionable whether the design of the SOS in its current form actually is necessary. It was designed to be floating on the surface of the pond to prevent theft. In consequence it implies the acquisition and fabrication of several parts, like barrels and a steel frame, which complicate the construction and lead to higher investment cost. The system could be simplified by not having it float in the pond. The solar panel and the electronics could be installed and attached on shore, while the pump could be placed in the middle of the pond by attaching it to a bamboo stick. In result, it would not only facilitate maintenance but also reduce hazards of drowning or electric shock, that come with the SOS being fully emerged in the pond. In addition to that, a water pump for the irrigation of the crops could also easily be connected to the solar panel.

Appendix E

Economics of all WLF

WLF 1	$	WLF 2	$
OpEx	413	**OpEx**	413
Income aquaculture	623.6	**Income aquaculture**	627
Income agriculture	343.8	**Income agriculture**	7.8
Annual profit	554.4	**Annual profit**	221.8
Monthly profit	46.2	**Monthly profit**	18.5
Hourly profit	0.77	**Hourly profit**	0.31

	years		years
Payback period	3.53	**Payback period**	8.84

WLF 3	$	WLF 4	$
OpEx	413	**OpEx**	413
Income aquaculture	623.5	**Income aquaculture**	430.8
Income agriculture	191.8	**Income agriculture**	54.2
Annual profit	402.3	**Annual profit**	72
Monthly profit	33.5	**Monthly profit**	6
Hourly profit	0.56	**Hourly profit**	0.1

	years		years
Payback period	4.87	**Payback period**	27.23

WLF 7	$	WLF 8	$
OpEx	413	**OpEx**	413
Income aquaculture	560.3	**Income aquaculture**	545.2
Income agriculture	38.6	**Income agriculture**	49.7
Annual profit	186.4	**Annual profit**	181.9
Monthly profit	15.5	**Monthly profit**	15.2
Hourly profit	0.26	**Hourly profit**	0.25

	years		years
Payback period	10.52	**Payback period**	10.77

WLF 9	$	WLF 10	$
OpEx	413	**OpEx**	413
Income aquaculture	439	**Income aquaculture**	631
Income agriculture	81.1	**Income agriculture**	194.7
Annual profit	107.1	**Annual profit**	412.7
Monthly profit	8.9	**Monthly profit**	34.4
Hourly profit	0.15	**Hourly profit**	0.57

	years		years
Payback period	18.3	**Payback period**	4.75

Economic and social feasibility of small-scale aquaculture ponds operated with the Sun-Oxygen-System

Zürcher Hochschule für Angewandte Wissenschaften

zh aw Life Sciences und Facility Management

Bachelor Thesis, Nathalie Pfister

Bachelor's degree program Environmental Engineering 2018

Introduction

Women in Cambodia suffer from gender inequalities in various areas and especially lack decision-making power [1]. While the country is exposed to an increasing risk of nutritional insecurity, based on decreasing wild fish catches [2] and a poor state of aquaculture [3], empowering women in the sector of aquaculture can mitigate these risks [4]. Thus, an interdepartmental project launched by the ZHAW, the AIT and Smiling Gecko Cambodia, has provided training and infrastructure for women to run their own small-scale aquaculture business. In order to improve oxygen levels in the waters of the fishponds, an off-grid solution called "Sun-Oxygen-System" was developed by the ZHAW.

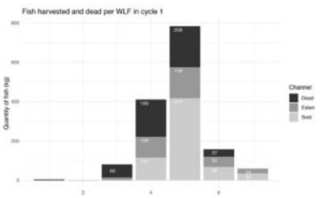
Woman Leader Farmer's pond with the Sun-Oxygen-System (Pfister, 2022)

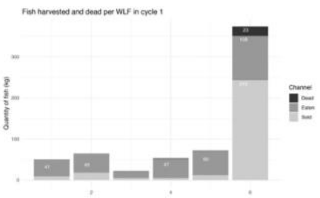
Methods

A trial was conducted from December 2020 until March 2022. It involved eight participants and ponds that were constructed for the trial. Two rearing cycles (cycle 1 without SOS, cycle 2 with SOS) were carried out by stocking a batch of fingerling for each cycle into the ponds. Data on fish and agricultural production was regularly documented and different surveys were conducted. Furthermore, the surveys also covered a category to assess the success of engaging women in aquaculture. Finally, on the basis of the conducted production data, the economic viability for each farm was calculated.

Aquaculture production

Individual fish growth was lower in cycle 2, which could be attributed to an increased concurrence due to natural reproduction of fish from cycle 1 that remained in the pond. The discovery that the fish naturally reproduced under given circumstances can be advantageous, since fingerlings must no longer be regularly purchased. Furthermore, they present an additional source of income. However, uncontrolled reproduction can lead to large size disparities among the harvested fish as well as to an increased competition for food and stunting of the original stock [5]. Consequently, it is important to accurately manage the fish stock [6]. **Mortality** decreased from a total of 32.36 % in cycle 1 to 2.7 % in cycle 2. Main **fish harvests** started in cycle 1 as of month four. In cycle 2 small amounts were continuously harvested over the whole cycle, while main harvests took place as of month six. The monthly harvests of small amounts in cycle 2 were possible because fish from cycle 1 remained in the pond.



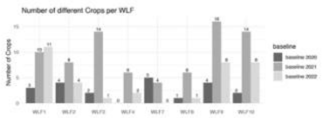


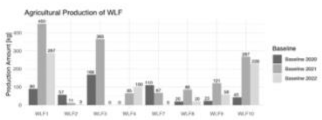
Efficiency of the Sun-Oxygen-System

Based on sampling of fish and the unknown effective biomass in cycle 2, no clear results could be obtained regarding the functionality of the SOS. However, it is likely that the technology has contributed to the drastic reduction of the mortality rate in cycle 2. Yet, further research should be conducted before the system is widely promoted for its benefits.

Agricultural production

After the construction of the ponds, the agricultural crops were significantly diversified, and the total production quantities increased by 115 %, which could be attributed to the increased water availability on the farm due to the pond. They have regularly used their pond to irrigate their agricultural crops.





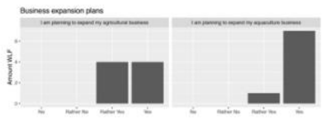
Economic viability

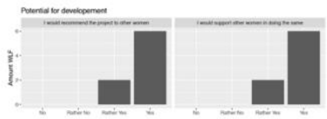
All farmers were able to cover the operational costs and furthermore, generated profits. Average annual profits including agricultural production amounted to 267.3 $. The economically most successful farmer reached an hourly wage of 0.77 $, which is just under the minimum wage of a factory worker. A determinant factor in increasing profitability was the agricultural production. Reducing the amount of commercial feed increased profits further. Depending on what is included into the financial calculations, the payback period for the capital investment on average ranges between 5.38 to 13.32 years.

Aquaculture		Aquaculture /Agriculture		Aquaculture/Agriculture/ Supplement feed	
	$		$		$
CapEx	1959.7	CapEx	1959.7	CapEx	1959.7
OpEx	413	OpEx	413	OpEx	315.8
Income aquaculture	560.1	Income aquaculture	560.1	Income aquaculture	560.1
		Income agriculture	120.2	Income agriculture	120.2
Annual profit	147.1	Annual profit	267.3	Annual profit	364.5
	years		years		years
Payback period	13.32	Payback period	7.33	Payback period	5.38

Success assessment

The social success assessment has shown that the farmers recognized the positive effects that a pond can provide. All of them planned to expand their aquaculture and agricultural production in the future. Moreover, they were open to support fellow women farmers in regards to developing their own aquaculture production.





The consumption of fish has increased by one day per week, which is an important attribute in light of Cambodia's stagnating fish catches.

Conclusion

Results underline that granting a seed fund for women to build their own aquaculture business does have various positive impacts. Moreover, the amount of seed funding does not necessarily need to cover the total capital investment costs of a pond. Some farmers have independently constructed a second pond on their land. Thus, granting smaller amounts of seed funding in order to buy a first batch of fingerlings and feed while providing educational material in form of workshops or online classes on aquaculture could already alleviate women's economic participation and reduce malnutrition.

Woman Leader Farmer with her harvest fish (Pfister, 2021)

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