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Review

Traditional Fish Hole Aquaculture System in Benin: Status, Challenges, and Research Prospects for Sustainable Development in Climate Change Mitigation

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Abstract: Fish holes called "whédos" are excavations performed near water bodies or in the flood plains of Beninese rivers in Africa for rearing fish. During floods, they are filled and naturally colonized by various fish that remain trapped during recessions. This literature review examines fishing, aquaculture, and fish reared in traditional holes in Benin. It reports on cartography, characterization, socioeconomic aspects, challenges, and status of improvement, and proposes prospects for improving this system. Peer reviews and gray literature were used to conduct the analysis. Our review highlights 19 papers reporting on 17 whédos aquaculture experiences based on the exclusion or inclusion criteria. These results indicate that many genera can be reared in whédos, suggesting that whédos offer the possibility of going beyond the production of *Clarias* and Tilapia in Africa. Furthermore, the exploitation of the whédos system is fairly profitable for fishermen and their households, at approximately US$ 1713 per household annually, used to finance agricultural activities, children's education, schooling, mitigating farmers' vulnerability to climate risks, and health care. However, in the past two decades, there has been a significant decline in the quantity of fish collected owing to the adverse effects of hydroclimatic changes, such as floods and prolonged droughts. Moreover, water eutrophication or pollution, the risk of climate change, and fishing methods have affected crop yield over the years. The implementation of Integrated Multi-Trophic Aquaculture or Integration Agriculture-Aquaculture in whédos systems can be an effective solution for improving profitability and sustainability. The knowledge gained from this review perspective should be helpful in directing future initiatives to grow and sustain this sector of the economy and to optimize its potential to provide food for future generations.

Keywords: whédos; eutrophication; climate change; innovation; sustainability

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1. Introduction

The role played by aquatic resources in food nutrition and security is increasingly recognized as a source of protein and as a varied source of bioavailable micronutrients and essential omega fatty acids [1]. Fisheries and aquaculture are key factors in food security and are vital for achieving sustainable development goals (SDGs) [1,2]. Fisheries and aquaculture production reached 214 million tons in 2020, including 178 and 36 million tons of aquatic animals and algae, respectively, showing a slight increase of 3% compared to that in 2018 (213 million tons) [1]. More than 157 million tons (89%) of this production is used for human consumption. The apparent global consumption of aquatic foods increased at an average annual rate of 3% from 1961 to 2019, almost twice the annual rate of global population growth (1.6%) during the same period [1]. The consumption of food products from aquatic animals per capita increased from 9.0 kg (in live weight equivalent) in 1961 to 20.5 kg in 2019 [1].

African fisheries and aquaculture production (excluding seaweed) decreased slightly by 1.2% from 2019 to 2020, whereas per capita consumption increased, contrary to other regions, which recorded continued growth of aquaculture production in 2020 [1]. Africa's contribution to global fish production in 2018 was estimated at 7% [3], although fish production is currently growing. The FAO [1] indicated that increased income and urbanization, improvements in post-harvest/catch practices, and changing dietary trends are projected to lead to an increase by 15% of the current consumption of aquatic food products, which was 20.2 kg in 2020, and estimated at 21.4 kg per inhabitant by 2030.

Recently, Benin recorded increasing growth in aquaculture production, with fish production reaching 5114.66 tons in 2018 [4,5]. To maintain this contribution and growth of the sector, the country should accelerate the implementation of innovations, investments, and particularly the enhancement of extensive systems to integrate breeding techniques. Despite this growth, statistics reveal an annual increase in the quantity of imported fish, which is significantly higher than national fish production [6,7]. This could be due to the rapid increase in population and income. Furthermore, over the past two decades, a significant decrease was observed in the quantities of fish harvested in natural environment. Inland fishing production decreased by 18,10% from 44,726 tons in 2020 to 36,631.2 tons in 2021 [4]. This may be because of the perverse effects of climatic changes, such as droughts and floods [8]. Other sources of the decrease over the years are dramatic environmental degradation, leading to a loss of biodiversity and a decline in fish stock [9–11]; overfishing; silting up of watercourses; endogeneity of resource degradation; degradation of fish stock; lack of fishing management policies; and fishing methods [12,13]. Therefore, to improve fish production growth in Benin, it is necessary to accelerate the implementation of innovations, invest, and particularly enhance extensive systems to integrate breeding techniques. Moreover, sustaining the production to meet the demand in the face of decreased fish populations in natural water resources and contributing to the global demands ahead will require the development of strong supportive technologies aquaculture production systems.

Benin has great potential for aquaculture with diverse aquaculture species (*Tilapia*, *Clarias*, *Heterotis*) and a range of aquaculture systems and techniques available, such as whédos, acadjas, ahlos, floating cages, ponds, and fish enclosures [14]. In addition, Benin has water reservoirs and hydraulic works constructions, such as human-made lakes (such as Lakes Ahozon and Bewacodji in the Southern region), with the main purpose of retaining water for various agropastoral uses [15,16]. The main objective of the creation of some water reservoirs was to offer human populations and livestock a permanent supply of water; however, over time, people began to develop traditional fishing and aquaculture activities and market gardening around these resources, which were formerly naturally stocked with fish. Therefore, it is necessary to increase national fisheries and aquaculture production through aquaculture promotion and rational management and the improvement of existing extensive systems.

Whédos are excavations performed near the water bodies or floodplains of rivers. During floods, they are filled and naturally colonized by various fish that remain trapped during a recession. This innovation of the craft fishermen of the Ouémé Valley comes from their endogenous knowledge of the ecological functions of the Ouémé River and its flooded plains. During the tide, fish migrate to flooded areas in search of spurs for bridging and eruption, and at the end, juveniles from breeding are trapped in these holes or plains [14,17–19]. During a recession, the floodplain area becomes rich in fertile land and fish [20].

Nowadays, the whédo system is becoming increasingly attractive to many fishermen due to several parameters such as its high yield, ease of management compared to others traditional systems, low investment requirements, availability of shallows and floodplains, the quality of species found in whédos and their appreciation by consumers; all this attracts research attention. However, this system of intensification of traditional fish production remains critical to control because of the high density of fish in farms and low water renewal; these conditions are met for the frequent occurrence of epizootics in farms [21]. Africa has 12 million hectares of floodplains [22]; if 1% of this superficies is developed as a whédos system with a yield of 1 t/ha/year, the potential output could reach 120,000 tons annually, which could reduce the demands. Despite this high potential, further studies are required to clarify the efficiency and sustainable productivity of whédos to build their resilience to climate change challenges. It is likely that declining water quality, particularly owing to low oxygen and high salt concentrations, is the cause of the significant decline in species richness during the dry season [23].

Climate change requires a reduction of greenhouse gas emissions in food production. By 2050, this initiative will improve sub-Saharan Africa's food security while simultaneously increasing the capacity of ecosystems to store carbon, which would reduce CO_2 emissions by 10–20% [24]. In Benin, extreme weather events such as droughts, extreme rainfall, heat waves, and floods are expected to become more intense and frequent, increasing the associated risks and impacts [25,26]. For example, a recent study reported variations in extreme precipitation from 1951 to 2014 in the upper Ouémé Valley, with prolonged droughts in the 1970s and the 1980s [27]. Other studies have highlighted uncertainties in the projection of extreme rainfall in the Ouémé and Mekrou Basin regions [28,29]. Therefore, there is an urgent need to strengthen adaptive capacities of developing countries to meet the challenges of climate change and protect global biodiversity [26,30,31].

Health management by breeders focuses on chemotherapy, with the risk of the accumulation of production residues. Overexploitation of fishing resources using prohibited gear, pollution, deforestation, and climate change are the main causes of production decline. Mastering this breeding system requires improvements in production techniques, creation of other strategies that can resist climate change, and good policy management.

Currently, there is an abundance of literature on how to improve aquaculture systems in more developed countries, with an increasingly visible contribution from researchers; however, in traditional African aquaculture, many questions remain unanswered, regarding the development of traditional fish holes used in aquaculture, particularly in Benin. For example, what is the state of knowledge on this subject in Benin? What work has already been performed to improve this system? What are the current innovations in reducing the risk of exposure to climate change? What are the research prospects of sustainable development in this field? What are the nutritional values of the fish produced in this system? What are the systematic characteristics of whédo in Benin? What is the exact mapping of whédos in Benin? This literature review addresses these questions.

2. Methodology

This literature review aims to provide detailed knowledge of the whédos aquaculture system in Benin. A three-step methodology was adopted, which included a search, document selection, and data extraction for analysis.

Search: Papers published as scientific articles, conference communications, theses, and technical reports on the subject were downloaded mostly from Agora and some from Google Scholar using keywords and expressions such as whédos, fish holes, floodplains, traditional fish farming, traditional aquaculture systems, extensive fish farming, water reservoirs, and the Ouémé Valley or river. The search was conducted in English and French with no publication date requirements. All the papers used in this review were from journals indexed on the Web of Science and Scopus.

Document selection: Duplicate papers were removed after the download, as well as some papers based on geographic limitations and the significance of the title and abstracts. The full manuscript was subsequently assessed. Potential studies were selected based on a set of inclusion and exclusion criteria. The main inclusion criteria were as follows.

- Relevance of the study: Papers must address information regarding the cartography of whédos in the Ouémé Valley and northern part of Benin, the characterization and productivity, the geographical location of the study, nutritional and health quality of fish produced in the whédos system, study design, profitability of the system, status of improvement, and challenges.
- Relevance and replicability of methodology: The methodology must be clear, comprehensible, and reproducible.
- Relevance of results: Documents must be usable for this synthesis.

One hundred twenty-four publications were included in this literature review after selection based on title, abstract, and inclusion criteria.

Data extraction and analysis: Peer reviews and gray literature were used to perform the analysis. After carefully reading the selected papers, key information and results were collected, filtered, and classified for conscious review. In particular, attention was paid to perspectives for further improvement. This historical perspective would be of great value in leading future efforts to develop, promote, and maintain this industry and boost its ability to become an efficient food source for future generations.

3. Traditional Pond Systems

3.1. Concepts and Evolution of Traditional Fish Holes

Fish holes are a form of extensive or traditional fish farming in Benin and are managed by fish farmers. Traditional ponds are the most essential method of fish production [21]. This is in line with concentration theory in the history of aquaculture, which states that "Flooded rivers create marshlands that support vegetation and aquatic organisms. During the dry season, the floodwater recedes, concentrating fish in depressions and plains. Fishermen catch fish regardless of size or type initially, but later transfer smaller ones to other areas. Aquaculture management begins by cultivating fish in embankments. This type of management is prevalent in extensive plains in Africa, combining capture fisheries and culture management" [31].

Two types of fish holes were distinguished: ahlos and whédos (Figure 1). Ahlos (Figure 1a) are channels dug up on the banks of rivers that constantly communicate with watercourses. They are built perpendicular to the watercourse, which directly supplies water owing to the movement of the tides. Toko [14] defined ahlos as a deep trench surrounded by floating vegetation. Whédos (Figure 1b,c) are fish holes located near rivers or in floodplains. During floods, they are filled and naturally colonized by various fish that remain trapped during a recession. This innovation of the craft fishermen of the Ouémé Valley comes from their endogenous knowledge of the ecological functions of the Ouémé River and its flooded plains. During the tide, fish migrate to flooded areas in search of spurs for bridging and eruption, and at the end, juveniles from breeding are trapped in these holes or plains [14,17–19]. Whédos differ from "Ahlos" because of the absence of permanent communication with the channel of the watercourse and their water supply once in the flooding period. They may reach >1 km long, 3–5 m wide, and 0.5–1.5 m deep. They are sometimes surrounded by floating plants before exploitation, which reduce the dissolved oxygen (DO) concentration in the pond. According to Floquet et al. [32], whédos are either holes or natural depressions, ditches, or ponds prepared in floodplains to trap fish. They are situated in marshes where water can still be maintained during a recession. This innovation started during the 19th century in the Ouémé Valley before it spread in 1980. Currently, whédos are being developed in the Ouémé Valley (southern Benin) and in northern Benin around the Niger Basin, the largest river in West Africa. Nets and transport pirogues were used for harvesting in whédo systems instead of branches that were formerly used. Indeed, stocking fish in closed floodplain ponds, such as the whédos in Benin, has already been used in different countries. It is a practical system for increasing the harvests of marketable fish and as an agro-cultural system in Rwanda [33] and Mexico [34]. Moreover, in Bangladesh, Ahmed [35] observed that stocking fish in small floodplains can increase the harvest by approximately eight times, whereas in Hungary, Pinter [36] found that it can provide a similar yield to extensive aquaculture in ponds. These extensive systems in Benin have three objectives: reconstitution by restocking because natural populations have been reduced by changes in their environment, particularly the critical degradation of habitats for reproduction (siltation or disappearance of spawning grounds, dams on watercourses hampering migration of spawners, pollution); the acclimatization of exotic species to create new stocks; and the acceleration of fish growth by breeding from the wild environment, often leading to overpopulation [21]. According to Kpadonou et al. [37], the whédos aquaculture system generates consistent income that finances agricultural activities and mitigate farmers' vulnerability to climate risks. Moreover, in recent decades, adaptation to climate change has become a serious challenge, and extensive fish farming is dependent on climate conditions, which constitutes a great challenge for producers.

Figure 1. Different fish hole systems in Benin: ahlo (**a**) and whédo during exploitation (**b**) and whédos after exploitation (**c**). The arrow indicates the entrance of the ahlo. Source: This study.

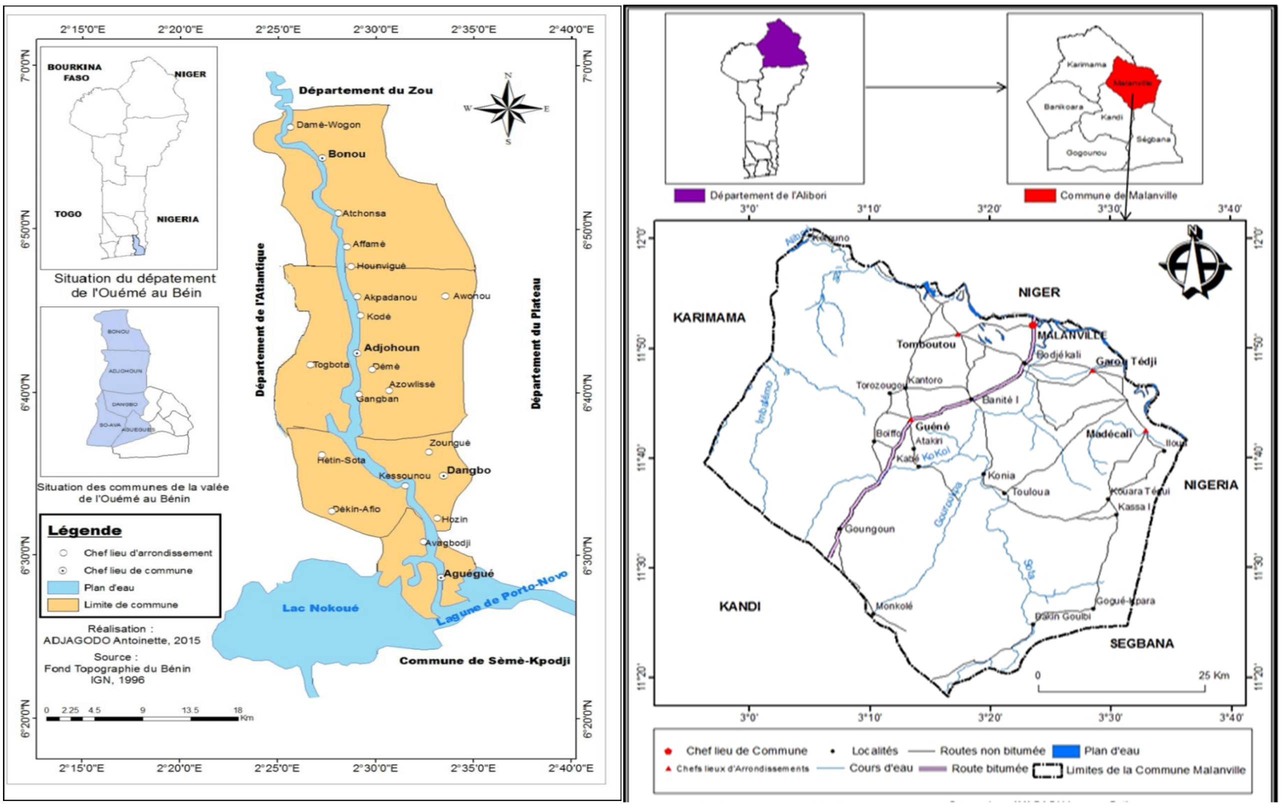
3.2. Typology of Whédos

Three types of whédo exploitation were observed in the Ouémé Valley. The most predominant is individual whédos, followed by family and community whédos [21]. A study by Chikou [38] in Agonlin Lowé village (in the lower Ouémé Valley) revealed that 60% of the whédos are family properties. Imorou Toko [39] stated that approximately 80% of fishermen obtain fish holes through land inheritance. Sogansa [40] revealed that 73.34% of whédos owners are in the age group of over 40 years.

There is currently no real characterization of whédos according to Lalèyè et al. [19], who concluded that current dimensions of a whédo depend on its initial dimensions and on the nature of the enhancements made to it after annual exploitation and on its age. The progressive degradation of the banks of whédos by water, most often their collapse, and the maintenance work conducted on the whédos modify the initial dimensions of the holes. However, Lalèyè et al. [19] suggested that whédo systems have lengths varying between 15 and 215 m (average 89.2 m) and widths between 3.5 and 4 m. Whédos more than 1 km long were also observed in Ouémé Delta, the depth of the holes was small, generally <1.7 m, and the water deep in the hole was an average of 40 cm [19]. Houenou Sedogbo [21] found whédos with average superficies of 332.67 m^2 and the highest of 5000 m^2 in the Ouémé Delta with an average depth of 1.15 m. These maximum water height values are lower than those recorded by Chikou [38] and, Imorou Toko [14], with values ranging from 0.4 to 0.66 m and from 0.4 to 1.1 m, respectively, in the lower Ouémé Delta. Dossou [41] revealed that these differences could be related to the nature of the watershed (convergence of water from runoff). In the northern part, approximately 500 whédos (locally called tschifi dais) are built covering a total surface area of 9.3 ha, hence reflecting the high acceptance of the system among the local population [23]. There is a gap between these findings, which depends on the period or season of the investigation. Therefore, data on this aspect must be obtained to further improve the system. The size of fish caught in whédos is relatively larger (7.3 cm to 62 cm, with an average of 20.7 cm) than those caught in other traditional systems within the country, such as Acadja [19]. The whédos identified in our review are rectangular, which is the predominant form, compared to square and irregular forms [21]. In contrast, Chikou [38] observed circular shapes in the lower Ouémé Delta.

3.3. Mapping of Whédos

Mapping allows for the correct and exact enumeration of a system and estimation of its real surface area of this production system. Figure 2 reports the areas of whédo development in Benin (a: Ouémé River Valley; b: Niger River Valley). To date, there is no exact data on the mapping of whédos in Benin. According to Lalèyè et al. [19], a systematic inventory of whédos was not performed because of the difficulty in accessing facilities and their high number. However, in 1969, an aerial survey estimated the extent of the zone of occupation of whédos at 365 km^2 with 3 ha/km^2 of plain land and reported 1095 whédos in the Ouémé Valley [42]. Noutaï [43] and Imorou Toko [39] reported >1000 whédos of various sizes in the Ouémé Valley. Lalèyè et al. [19] estimated the occupation area of the whédos at 3.2 ha/km^2 of the plain with a total whédo area of 1168 ha. Houenou Sedogbo [21] recorded an average number of 3.5 whédos per household for the same area, which is lower than that found by Imorou Toko [39]. These results should be updated to improve production. Conversely, in the northern part of Benin, approximately 500 whédos (locally called tschifi dais) were enumerated, covering a total surface area of 9.3 ha, hence reflecting the high acceptance of the system among the local population [44].



(**a**) (**b**)

Figure 2. Whédos development areas in Benin ((**a**): Ouémé River Valley; (**b**): Niger River Valley). Source: Adjagodo et al., 2017 [45].

Through these studies, it was observed that there was a progressive increase in the whédos system and some disparity among the results, varying from one study to another. Therefore, there is a need to systematically map whédos using modern technologies to accurately update their estimates and plan improvements in production more efficiently.

3.4. Importance of Traditional and Extensive Fish Farming

There are three types of fish farming systems: extensive, semi-intensive, and intensive. In real environments, extensive fish farming includes uncontrolled breeding and rearing systems in which feed inputs and fish feed are almost absent [46]. Human intervention only makes arrangements favorable to the survival and preservation of species [40]. In extensive fish farming, fish are fed natural food present in the environment as well as supplements provided by farmers.

Extensive farming represents 75% of the world's fish production, which is the major sector for the production of food resources, and generally offers neighboring sectors adapted to fish demand, both in urban and rural areas [47]. Traditional farming offers more sustainable alternatives to agrobusiness and intensive agriculture by relying on ancestral knowledge and experience in natural ecosystem use [47]. In Asia, extensive fishing accounts for approximately 80% of livestock production and is an important part of family farming [47]. Also known as traditional fishing, it is developed with little financial resources in a discreet manner, but contributes enormously to the progress of developing countries and allows for better valorization of production factors [47]. The integration of fishing into peasant farms offers interesting potential in the intertropical zones.

In Benin, Cameroon, Côte d'Ivoire, and several other African countries, traditional and extensive fish farming plays an important role in the fight against poverty and sustainable development of family farms. Furthermore, in Bangladesh and Cambodia, family or traditional catfish farming contributes significantly to poverty reduction and effectively improves human nutrition [47]. However, due to their sometimes "confidential" nature, the social and economic impact of these productive systems in the rural world is often "ignored" in national development policies whose resources are mainly focused on industrial aquaculture or small- and medium-sized enterprises [48].

Intensive fish farming is more export-oriented or intended for wealthy clienteles, as opposed to family fish farming, and one must consider the contribution of family fish farming to the conditions of its independent development and local added value [49]. However, it must be acknowledged that "successful" extensive fish farming is profitable and sustainable. However, in various countries such as Guinea and Côte d'Ivoire, the barriers to the development of economically viable and practical fishery activities on family farms have been broken, which has many local impacts [50]. Family fish farming is mainly practiced by small fishermen with limited resources, and can therefore be used as a potential tool for improving nutritional quality and food security. Extensive fish farming is the most prevalent form of the system practiced by many fishermen in Sub-Saharan Africa [49]. However, efforts to develop fish farming in Benin have not yet reached a large scale [23]. One reason for the failure of fish farming is the lack of consideration of the social and cultural aspects of continental fisheries and aquaculture, particularly in the absence of basic endogenous knowledge and constraints of natural resources [50]. Therefore, fish farming should be developed by modifying and improving existing traditional or extensive systems, such as fish holes or whédos systems, and Acadja in Benin. Traditional fish hole systems inspire admiration and require development and improvement considering local realities, particularly in the Ouémé Valley (South Benin), where fish holes have become increasingly attractive to full-time fishermen [14,51].

3.5. Socio-Economic Impacts of Whédos System Aquaculture

Whédos constitute an important fish farming environment in Benin, far beyond enclosures, classic ponds, floating cages, and concrete basins [52,53]. The data on the socioeconomic study of this system have allowed us to understand that the whédos for fishermen of the Ouémé Valley or Niger Basin are a source of prestige. Indeed, the land and financial restrictions required for their construction limit several fishermen from accessing the property. In the mind of the Ouémé Valley fishermen, a whédo today ensures Pacific retirement because he can rent it out when he is not physically able to exploit it. Moreover, the exploitation of the whédo system culture in the Ouémé Valley and Niger Basin is a profitable business for private fishermen households. This activity is generally conducted once a year but can yield 182,000 (≈US$ 303.3) to 572,720 Fcfa/ha (≈US$ 954.53) per household, which denotes approximately 27% of their annual income [40]. In northern Benin, this activity is also profitable because the profit-to-cost ratio is >1 and the net annual income can exceed a million francs (1027, 800 Fcfa ≈US$ 1713) [54]. Nonfon [18] highlighted the socioeconomic importance of fishing in whédos, an activity practiced once a year. Any innovation that improves performance will therefore receive approval. According to Kpadonou et al. [55], the whédo aquaculture system generates consistent income that finance agricultural activities, children's education, and schooling and mitigates farmers' vulnerability to climate risks. Income provides healthcare, purchase of motorcycles, construction of housing, and supply of manufactured goods [8].

3.6. Physicochemical Variables in Whédos

DO is a vital parameter and the most important environmental stress factor in aquaculture. Hypoxic stress induces many behavioral and physiological changes in fish [2]. Water quality assessment is vital to improve the productivity of fish in whédos in the Ouémé River by stocking and culturing during drought periods. Despite its importance, minimal data are available regarding the water quality in this system. Imorou Toko et al. [56] demonstrated no significant differences in pH and nitrites in the whédos system compared with those in natural rivers; however, temperature, DO, transparency, and microalgal biomass were significantly lower in the whédos system than in the river channel. However, the variability in water quality in the whédos system depends on its size, width, and depth with water height [56]. Moreover, all the fish species observed in whédos, namely *Clarias*, *Polypterus*, *Xenomystus*, *Parachanna*, *Ctenopoma*, *Protopterus*, *Malapterurus*, and *Brienomyrus*, displayed adaptability for survival in hypoxic environments [23,56]. Consequently, these indices limit the potential for stocking many fish species during the drawdown period [56]. Therefore, there is a need for a clear typology and characterization of whédos to enhance this system.

A study on physicochemical characteristics of whédos water showed a variation in temperature between 26.30 °C to 30.00 °C [19]. According to Noumon et al. [57], this temperature range fits perfectly with ideal living conditions for fish species. This temperature fluctuation was similar with that found by Lalèyè et al. [58] in the Ouémé Delta. The pH reported for whédos water varied between 5.44 and 7.26 in Ouémé Valley [21,39,40] and from 6.42 to 7.98 in the Niger River Valley at Malanville (Northern part of Benin) [42]. These pH values showed a general trend of whédo water towards acidification. This should be managed to ensure optimal pH conditions (from 6 to 8) for fish survival and growth in whédos [59] by preventing the input of organic matter from agricultural waste directly discharged into the whédos area and acadja parks, whose decomposition produces a large amount of carbon dioxide, decreasing the pH.

The values obtained for turbidity in whédos water were relatively high [21,39,60]. This high-water turbidity is consolidated by the variation profile of electrical conductivity, which are also relatively high (electrical conductivity >100 µS/cm) in whédos [21]. The average conductivity in the whédos is 96.65 µs/cm with a minimum of 10 µs/cm and a maximum of 350 µs/cm [41]. These results reflect highly mineralized water that is highly loaded with dissolved matter, leading to the low water transparency obtained in the system. Nitrites derived from the influence of nitrates on bacteria in whédos presented concentrations higher than the admissible limit of 0.006 mg/L, corresponding to the lower threshold of acute toxicity and constituting an absolute problem for water quality [21,61,62]. The DO level in whédos system is 2.5 mg/L in average in Northen part [63], 2.3 mg/L in South [14] and the transparency is 19.0 cm [14]. The low levels of DO and high concentrations of nitrates in these waters could be the sources of the high concentrations of nitrites and ammonia. Houenou Sedogbo [21] observed high concentrations of phosphorus in whédos. This can lead to serious ecological problems due to eutrophication. The high electrical conductivity and high turbidity of the water could then be due to eutrophication, leading to excessive growth of algae and depletion of water in oxygen. This was a consequence of an increase in the mortality rates of some species. The accumulation of fertilizers, particularly phosphorus, in agricultural soils is a probable cause of river contamination in rural areas [64], and excess in phosphorus causes eutrophication [65].

3.7. Fish Species and Productivity in Whédos

Despite the low oxygen concentration, these whédos used to trap wild fish in flooding periods shelter diverse fish genera and families [14,17]. Lalèyè et al. [19] distinguished 12 fish species that belong to 9 families in whédos in the southern part of Benin, whereas Hauber [23] identified 15 species at the end of the dry season in whédos at the northern part of Benin. It remains to be seen exactly when this research is conducted (rainy season, beginning, or end of the dry season), whether the methodologies used are clear and reproducible, and whether these data are updated over time. Therefore, the categorization of whédos species must be updated for efficient aquaculture. Table 1 presents the different species found in whédos in southern and northern Benin. Such fish farming is mostly rural and obviously oriented to the immediate needs of families; however, it is currently expanding.

Table 1. Ichthyological diversity of the whédos of the Ouémé delta (South) and the Niger basin (North) of Benin.

Family	**Species Found in:**	
	North	**South**
Clariidae	*Clarias gariepinus* (Burchell, 1822) *Heterobranchus longifilis* (Valenciennes, 1840)	*Clarias gariepinus* (Burchell, 1822) *Clarias ebriensis* (Pellegrin, 1920)
Protopteridae	*Protopterus annectens* (Owen, 1839)	*Protopterus annectens* (Owen, 1839)
Polypteridae	*Polypterus senegalus* (Cuvier, 1829)	*Polypterus senegalus* (Cuvier, 1829)
Osteoglossidae	*Heterotis niloticus* (Cuvier 1829)	*Heterotis niloticus* (Cuvier 1829)
Mormyridae	*Brevimyrus niger* (Günther, 1866)	*Brevimyrus niger* (Günther, 1866)
Anabantidae	*Ctenopoma* sp.	*Ctenopoma petherici* (Günther, 1864) *Ctenopoma kingsleyae* (Günther, 1996)
Channidae	*Parachanna obscura* (Günther, 1861)	*Parachanna africana* (Steindahner, 1879) *Parachana obscura* (Günther, 1861)
Claroteidae	*Auchenoglanis occidentalis* (Valenciennes, 1840)	-
Cyprinodontidae	*Epiplatys spilargyreius* (Duméril, 1861) *Nothobranchius kiyawensis* (Ahl, 1928)	- -
Cichlidae	*Hemichromis* cf. *letourneauxi* (Sauvage, 1880) *Oreochromis niloticus* (Linnaeus, 1758) *Sarotherodon galilaeus* (Linnaeus, 1758)	
Mochokidae	*Synodontis schall* (Bloch & Schneider, 1801)	
Malapteruridae		*Malapterurus electricus* (Gmelin, 1789)
Notopteridae		*Xenomystus nigri* (Günther, 1868)

The productivity of whédos is related not only to their surface area but also to the abundance and duration of annual floods. From 1955 to 1958, this production was high in Ouémé River Valley (South of Benin), averaging 2.12 t/ha/year, but decreased in 1968 to 1.57 t/ha/year, 1.37 t/ha/year in 1970, a slight increase to 1.60 t/ha/year in 1988, and further decreased to 0.8 and 0.63 t/ha/year in 2003 and 2007, respectively [18,19,43,66] (Figure 3). However, a yield of 1.31 t/h/year was found by Lalèyè et al. [19], 1.58 t/ha in 2013, which was done only in high delta river [41]. The degree of oscillation of the curve (Figure 3) on the evolution of productivity over the years in the Ouémé Valley leads to several hypotheses or questions. Are the analysis methodologies clear and reproducible? The divergence of research environments could affect the results, as the physicochemical parameters and typology of these whédos vary according to the environment; however, it is unclear whether the author refers to single whédos or to the entire water surface area. In the northern part of Benin, when linked to the entire biomass harvested from the entire water surface of the exploited whédos, the annual average yield reached 3 t/ha in 2008 and 2.1 t/ha in 2009 [23]. This lower annual yield observed in the Ouémé Delta during some period may be due to their far higher density compared to the whédos in the northern part and their feeding regime [23]. Nonfon [18], Lalèyè et al. [19], Gbêhi & Adédiran [8], and Aissi [67] noticed a net decrease in in whédos yield from year to year. This process must be improved to ensure sustainability. The harvest period occurs from December to June, particularly in February, and in all cases, before the longest raining period. Therefore, the exploitation cycle of a whédo begins when the water level drops (November), and ends before the water level rises or heavy rains occur (June). The climate in the southern part of Benin is subequatorial, characterized by two rainy seasons, the longest of which extends from April to July, with the average maximum rainfall reaching 354.54 mm in June, and the shortest from October to November, with the average maximum rainfall reaching 139.03 mm in October. There are two dry seasons, the longest of which extends from December to March and the shortest from August to September. However, in the northern part of Benin, the climate is Sudanian (unimodal) with two seasons (rainy: May to October and dry: November to April). During the last decade, several floods have affected the country and two (2021 and 2020) have affected the Ouémé Valley, where most whédos are located. According to case research of the 'Ebe'-fishery in Ghana, a system similar to fish holes, the annual whédos yield is between 13.3 and 26.7 t/ha water surface [50]. Large wetlands stocked with carp species, similar to whédos in India, yield better than natural production, increasing from 300 to 2000 kg/ha/year [68]. Stocking in small waterbodies in Burkina Faso, similar to whédos with 20 kg/ha (800 fingerlings) of *Oreochromis niloticus*, increased the harvest from 23 to 269 kg/ha [69].

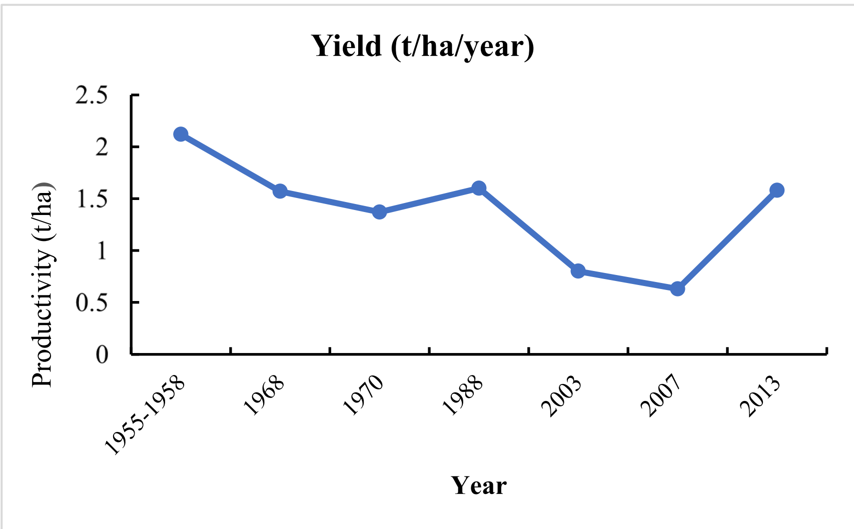


Figure 3. Variation in annual yields in Ouémé River. Source: This study.

The low production of whédos in Benin or the decline in yield could be related to a reduction in the natural environment (Ouémé River) due to heavy fishing. Other sources of the decrease over the years are dramatic environmental degradation, leading to a loss of biodiversity and a decline in fish stock [9–11]; overfishing; silting up of watercourses; endogeneity of resource degradation; degradation of fish stock; lack of fishing management policies; and fishing methods [12,13]. Another crucial aspect of this decline is climate change. Therefore, improving the productivity and resilience of whédos through the co-construction of new and more resilient adaptation systems is essential for enhancing their yields.

3.8. Previous Improvement in Zootechnical Performance of Fish Farming in Whédos

Little is known about improvements in the zootechnical and economic performance of fish farming in whédos. Gbêhi & Adédiran [8] worked on climate change-resilient innovations, including the use of mesh belts and happas (Figure 4). However, according to their results, six of the eight belts installed did not function properly despite compliance with the dimensions (pile depth and spacing). Many observations have been made, and hypotheses have been put forward by these authors for effective improvement. Imorou Toko [14] promoted *C. gariepinus* and *H. longifilis* production in the whédos system, demonstrating that these species could grow at a density of 21 fish/m^3 in whédos with good performance, similar to that in ponds. Furthermore, Elegbe et al. [70] evaluated the effect of co-culturing *C. gariepinus* and *O. niloticus* fry on the growth of both species bred in happas placed in whédos and concluded that the improvement in fry growth and feed utilization depends on the quality of the feed. Therefore, the feed is a determining factor for system improvement. In contrast, Elegbe et al. [71,72] determined the advantages of compensatory hyperphagia in *O. niloticus* and *C. gariepinus* in optimizing productivity, where samples of these fish were fed three times a day, once every 12, 24, and 48 h. The results showed that fry fed once at 12 h and 24 h showed complete compensatory growth. In conclusion, compensatory hyperphagia reduces production costs and improves fish health during a 24-h fast. These studies focused on fry rearing in monoculture in happas. The effect on juveniles or adults in uncontrolled polyculture remains a challenge, as the intensity of compensatory growth depends on several factors such as age, species, sex, and developmental stage [73,74].

Figure 4. Co-construction in whédos with happas in improvement at Agonli-lowé. Source: Gbêhi & Adédiran (2021) [8].

3.9. Health Status and Nutritional Quality of Fish Produced in Whédos

Nutritional and sanitary qualities are important factors in consumer choice of species. Minimal work has been done on the sanitary and nutritional quality of whédos species in Benin; however, Houenou Sedogbo et al. [21] reported on the parasitic aspect, and Radji et al. [75] on the state of documentation on fishing, aquaculture, and microbiological profile of *C. gariepinus* and *O. niloticus*, two fish species reared in the whédos of the upper Ouémé Delta. However, fish reared or harvested from whédos, particularly *C. gariepinus*, *P. obscura*, *Hepsetus odoe*, and *O. niloticus*, are gaining momentum because of their hardiness and quality of their flesh, which is highly appreciated by the Beninese population [21,76]. Most of the species harvested from the whédos are smoked. Smoking is the primary method used to preserve the nutritional quality of fish [77,78]. This traditional practice has been used for generations worldwide to preserve perishable products and diversify food options [77,78]. Smoking is often combined with cooking, drying, and salting [79,80]. It enhances flavor and affects the color of fish, providing a desirable experience for consumers [81].

Fish from various aquaculture systems are subjected to several factors. Parasitism, variable pathogens, water quality, and other microorganisms have been recorded in the

Ouémé Valley [21,82], which led to an assessment of the health profile of these fish in farmed and wild environments. The identification of monoxenous and heteroxenous parasites [21,83] has revealed the presence of numerous disease vectors in the ecosystem that can lead to the loss of value and resources. Parasite prevalence could be a significant factor in the depreciation of the quality of fish reared in whédos in Benin, as parasites can remove environmental toxins when hosts ingest them [84]. Another pathway of contamination is agricultural pesticides, particularly in the northern basin, which enter waters of the southern basin. Agbohessi et al. [85,86] suggested that organic pollutants seriously impair endocrine regulation and cause harmful damage to the liver and gonads.

Houenou Sedogbo et al. [21] reported on the parasitic aspects of these species found in Whédos, which should give rise to reflections for further research. According to Houenou Sedogbo et al. [21], the exploitation of whédos and associated anthropogenic activities contribute to the pollution of the floodplain with organic and chemical pollutants. This pollution creates stressful conditions that render fish more vulnerable to parasitic infections. Furthermore, the stagnant nature of the water in whédos means that they are heavily laden with organic matter, encouraging the proliferation of macroinvertebrates such as annelids, mollusks, and insects, which serve as intermediate hosts for many parasites. Karvonen et al. [87] suggested that parasite distribution may be due to the host-parasite relationship, but also to abiotic factors such as DO, pH, and temperature. Edema et al. [88] and Radji et al. [75] revealed that reduced oxygen levels in water, increased organic matter in water, and poor environmental conditions are some of the factors that favor parasitic infestation in fish. Moreover, according to Ferreira et al. [89], fish species with a broad diet or an omnivorous tendency, such as *C. gariepinus*, are more susceptible to high intestinal parasite prevalence. This feeding behavior opens the door for parasitism and the development of several pathologies in these fish species [90]. Houenou Sedogbo et al. [21] also observed the influence of season on the distribution of parasites, with the fish examined being more parasitized during periods of high water than during periods of low water.

The analysis of the whédos system in the upper Ouémé Delta in southern Benin reveals the presence of rich parasitic fauna. Eleven species/taxa of parasitic metazoans were identified [21]. Some of the parasites found in whédos, such as *Clinostomum* sp., are zoonotic parasites that pose a problem for public health [91,92] and consumer rejection [93]. Under these conditions, the presence of parasites in this organ can interfere with respiration or ion exchange processes, thereby affecting the overall physiology of the fish and potentially leading to death. Indeed, the parasitic species observed by Houenou Sedogbo et al. [21], particularly monogeneans, are known to cause mortality [75,93,94]. These parasites can also increase the susceptibility of fish to secondary infections [95]. Co-infections can exacerbate the risk of epizootics [96,97]. The presence of endoparasites, as noted by Houenou Sedogbo et al. [21], should not be underestimated. These metazoans can annihilate fish reproductive capacities [92,98], increase susceptibility to predation [99,100], or damage host tissues [101].

3.10. Main Challenges in Whédos System

3.10.1. Potential Impacts of Climate Change

Benin has experienced a significant increase in climate-induced extremes, affecting people and agricultural activities. Climate change has been experienced in the country, with the latest decades marked by rising temperatures, reduced rainy days, and changes in precipitation patterns leading to more frequent and intense droughts and floods [102]. Between 1991 and 2021, the annual mean temperature in the country has increased by approximately 1.2 °C, whereas annual rainfall has decreased from 184.94 mm to 158.47 mm. Over the past 60 years, distinct patterns of inter-annual precipitation variability have been observed [102]. Years such as 1977 and 1983 manifested prolonged droughts and particularly dry conditions, whereas others, such as 1962, 1968, 1988, 1997, 1998, 2007, 2010, 2013, 2019, 2020, and 2021, registered instances of severe flooding. These changes in climate patterns have a significant impact on agricultural productivity, such as the whédos in Benin, which threaten food security [102].

Potential climate change encompasses all climate parameter changes that can occur because of increased greenhouse gas emissions into the atmosphere. It represents the overall greenhouse gas emissions over a 100-year period, calculated based on the characterization factors established by Forester et al. [103] and expressed in kg-CO_2 equivalent per functional unit of product. In general, there is a broad consensus that climate change poses a threat to the development of Africa, where most of the population depends on subsistence and rain-fed agriculture [31,104–107].

Benin was mainly affected by six climate hazards, despite variations in the estimates of climate parameters. These hazards include floods during the rainy season and short dry season, delays in the long rainy season, pockets of drought, strong winds, heat waves, and sea level rise [26,31,108].

Although policymakers are aware of the challenges related to climate change, the strategies and policy tools to address them are often limited by the lack of adequate information and coordination frameworks. The same is true in Benin, where it is not always easy to know the causes and effects of climate hazards and their consequences on key development sectors, making it difficult to plan adaptation strategies at the national and sectoral levels [31]. Over the last 50 years, the average temperature has increased in Benin [108], unlike rainfall, which has steadily decreased the number of rainy days with the shortening of the short rainy season since the 1970s [109]. These climate changes have a negative impact on agriculture, resulting in reduced yields, disruptions to the crop calendar, and rural exodus [110,111]. According to Yegbemey et al. [110], seed diversification is a cost-effective adaptation option for farmers in northern Benin; however, its effectiveness depends on their experience, membership in farmer organizations, and access to climatic information. Despite the effectiveness of the current adaptation measures in the agricultural sector, their long-term viability remains uncertain. Therefore, it is essential to develop sustainable adaptation strategies to address future challenges related to climate change. There is also a need to strengthen research and data collection to better understand the impacts of climate change and to develop more effective adaptation policies and strategies.

3.10.2. Eutrophication

The enrichment of water resources with biogenic nutrients, particularly phosphorus and nitrogen, which promote photosynthesis but also change water quality, is known as eutrophication [112]. As mentioned above, high phosphorus and nitrogen concentrations of were observed in the whédos system. Furthermore, this constitutes a major impact category for whédos production systems, owing to the management of animal waste and the quantities of phosphorus and nitrogen mobilized for crop fertilization directly discharged into aquatic ecosystems. According to recent research, the degree of this influence varies depending on the breeding type [112].

However, potential eutrophication in the whédos production system constitutes the main impact category, and it is imperative to thoroughly examine fish farm discharge when they are in the inventory stage of their life cycle. Although this is not yet a resolved issue, the quantification of discharges remains a concern, particularly in traditional fish farming systems with semi-intensive ponds [113,114].

Low DO levels can be induced in whédos due to the low photosynthetic activity of aquatic plants [115]. Houenou Sedogbo [21] observed a high phosphorus concentration in whédos. Numerous authors believe that mixed farming or polyculture, which involves plants and animals, is a good way to reduce the impact of this aquaculture category without using more energy. This is because other aquaculture species, either plants or animals, would value a significant portion of nutrients released by aquaculture systems [116,117].

3.10.3. Fish Farm Discharges and Wastes

Generally, terrigenous inputs, dead fish, and inputs that fish do not "use" before or after processing are the main causes of discharge from fish farms [118]. Some of these factors originate from rainfall runoff, the importance of which depends on the topography of the watershed or the site [119]. Regardless of the system, discharges can be divided into three types: gaseous, diffuse (mainly in dissolved form), and point (solid, particulate, or dissolved), all originating from different compartments of the ponds. Their quality and quantity depend on the breeding system, feeding, feed composition (digestibility), and physical and climatic conditions of the environment [113,120]. As these factors are uncontrollable in the whédos system, further research is necessary to improve the system.

3.10.4. Water Acidification and Loss of Quality

Agricultural and industrial activities produce acidic pollutant gases that enrich the atmosphere with nitric and sulfuric acids after oxidation. This generally falls to the ground in the form of acid rain. Acidifying pollutants have a wide range of effects on groundwater, soil, living organisms, surface water, ecosystems, and materials. Basset-Mens [121] evaluated its level using the "RAINS" acidification model, which determines the effects of nitrogen and sulfur based on ecosystem properties. Acidification is expressed as kg-CO_2 equivalent. Its assessment in an intensive fish farming system revealed that it is linked to 61–82% of food production owing to gas emissions from the agricultural phase of ingredient production. However, this also depends on the type of farming [111].

Water parameters in whédos undergo significant changes throughout the year, leading to adverse environmental conditions during the dry season. These conditions include high nutrient inputs, particularly nitrite, and high electrical conductivity, resulting in low species composition [64]. Low DO concentrations, high electric conductivity, and high nitrite concentrations limit the choice of species for aquaculture, particularly for air-breathing or adapted fish species such as *C. gariepinus*, *H. longifilis*, and *P. annectens.* High turbidity also reduces light penetration and photosynthetic activity, destroying beneficial bottom organism communities, irritating fish gills and affecting sight-feeding fish [122]. Tolerance levels for fish cultures vary depending on the species; however, the nitrite concentration in whédos exceeds the tolerance range of many fish species. Therefore, maintaining water quality and reducing turbidity levels are crucial to ensure fish health and survival.

Density remains a major challenge in the whédos system, despite the Imorou Toko [14] indicating an efficient density for species such as *C. gariepinus* and *H. longifilis* in whédos (21 fish/m^3), because there is no systematic and time-consistent characterization of these fish holes. Therefore, further studies should be conducted using these new technologies. Another challenge faced by farmers is the difficulty in accessing credit to increase their production.

4. Prospective for System Sustainability

The development of an extensive system for fish culture, such as whédos, needs to be sustained in Benin to meet market demands, enhance consumer health, boost profits, protect aquatic environments, ensure welfare, and reduce the vulnerability of farmers (Table 2). The whédos system may also play a crucial role in global food security, nutrition, and livelihoods related to SDG 1 (No Poverty), SDG 2 (Zero Hunger), and SDG 14 (Life Below Water) [123]. These perspectives (Table 2) are linked to the strategic objectives SO1 (promoting a resilient system of governance of development sectors), SO_2 (promoting a resilient system of management and exploitation of natural resources), and to the strategic orientations SO_2 (promoting the rational and sustainable management of natural resources and ecosystems) of the National Plan for Adaptation to Climate Change in Benin [124].

Prior to addressing some areas for improvement of the whédos system in Benin, it would be important to update data on whédos through a systematic characterization of this system and its mapping using new technologies to excite investors and governments to invest in its improvement and sustainability.

Table 2. Prospects for whédos system sustainability.

Subject Area	Research Questions and Recommendations
Develop Integrated Systems into the Whédos	- Cultivate adapted species in this system (such as *Clarias*) resilient to disease outbreaks or environmental fluctuations - Innovate by creating habitats for various species - Initiate a system by combining different aquatic organisms to provide a diverse range of nutritious products
Fish Health and Quality	- Characterize the histopathology associated with infected organs from fish in whédos - Assess the bioaccumulation of heavy metals and pesticides in fish and sediments collected from whédos - Have good sustainable aquaculture practices in whédos by strictly regulating the use of agricultural by-products - Highlight the health implication of fish parasites found in the whédos
Conservation and Climate change mitigation	- Reduce climate change and disaster risks through integrated and comprehensive approaches, including cross-sectoral collaboration - Conserve, sustain, and enhance aquatic biodiversity in the whédos system through species selection and genetic improvement
Support for Research, Innovation,and Management	- The Government should establish legal regulations on this traditional system and facilitate access to credit to the farmers - Develop new technologies such as digital credit assurance systems based on farmers' production history to help small-scale farmers secure loans - Institute a framework for planning and managing the development of whédos fishery systems - Create new opportunities and encourage diversification, reducing exploitation and degradation of natural resources - Describe the interaction between whédos systems and SDGs

5. Conclusions

Currently, the development of fisheries depends on diversification of fish species, which promotes the domestication of indigenous species in farming areas. This study reveals the potential for the aquaculture sector to grow and provide jobs through the whédos aquaculture system in Benin. This traditional aquaculture system in fish holes, called whédos, helps floodplain farmers improve their education, reduce poverty, and enhance food security, which are in line with SDGs. In general, the prospects of the whédos system culture in Benin seem relatively promising if more research and work are conducted to improve the system. Many species are found in whédos and can be reared. Therefore, aquaculture in Benin should be developed through the modification and improvement of extensive systems such as whédos. Some challenges in improving this system include water pollution, environmental hypoxia, management problems, and the risk of climate change. However, all these challenges can be addressed through innovation, such as integrated multitrophic aquaculture, hydroponics, or aquaponic systems. The insights of this perspective review can guide future economic initiatives to develop and sustain this sector, maximizing its potential to provide food for future generations.

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