Description and Improvement of the 'Whedo'-Aquaculture-System in Malanville (North of Benin)

DISSERTATION ZUR ERLANGUNG DES

NATURWISSENSCHAFTLICHEN DOKTORGRADES

DER BAYERISCHEN JULIUS-MAXIMILIANS-UNIVERSTITÄT WÜRZBURG

VORGELEGT VON

MELANIE E. HAUBER

GEBOREN IN SINGEN AM HOHENTWIEL

WÜRZBURG May 2011

Eingereicht am:

Mitglieder der Prüfungskommission:

Vorsitzender: Prof. Dr. Th. Dandekar

1. Gutachter: Prof. Dr. K. Eduard Linsenmair

2. Gutachter: Prof. Dr. J. Tautz

Tag des Promotionskolloquiums:

Doktorurkunde ausgehändigt am:

Gewässer, ihr seid diejenigen, die uns Lebenskraft geben.

Helft uns Nahrung zu finden,

so dass wir andere mit großer Freude betrachten können.

(Rama Kishan Sharma)

TABLE OF CONTENTS

Chapter III
Current Management of the Whedo-Aquaculture-System

Chapter IV
Improvement of the Productivity of the Whedo-Aquaculture-System

List of Figures

Chapter I

Chapter II

CHAPTER III

CHAPTER IV

GENERAL CONCLUSION & OUTLOOK

GENERAL APPENDICES

List of Tables

Chapter II

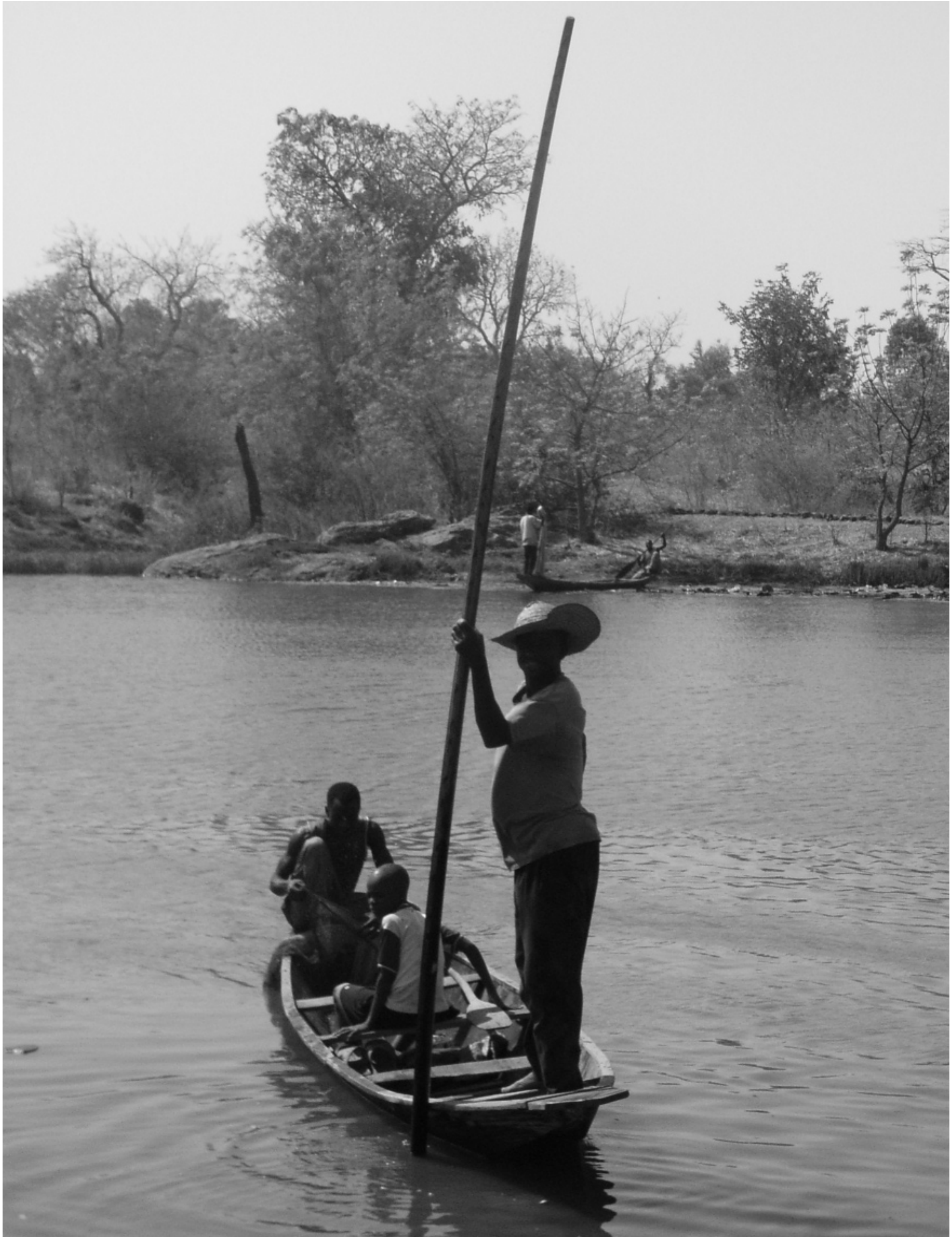
Chapter III

Chapter IV

GENERAL APPENDICES

LIST OF ABBREVIATIONS

BCR	Benefit-Cost-Ratio
BWG	Body Weight Gain
C	Carbon
Ca	Calcium
CeCCPA	Centre Communale pour le Promotion Agricole
CF and ch-fl	Channel-flooded 'Whedos'
CH	Carbonate Hardness
CLCAM	Caisse Local de Crédit Agricole Mutuel
°dH	Deutsche Härtegrad
DO	Dissolved Oxygen
FAO	Food and Agricultural Organisation
FC	Fixed Costs
FCE	Feed Conversion Efficiency
Fe	Iron
fl/dc	River-flooded disconnected
FO	Feed Offered
GE	Gross Energy
GR	Gross Return
IC	Incidence of Costs
K	Potassium
MDS	Multi Dimensional Scaling
Mg	Magnesium
N	Nitrogen
Na	Sodium
NB	Net Benefit
NH_4	Ammonium
NO_2	Nitrite
NO_3	Nitrate
P	Phosphorous
PADPPA	Programme d'Appui au Développement Participatif de la Pêche Artisanale/ Participative artisanal fisheries development support programme
PADFA	Programme d'Appui au Développement des Filières Agricoles/ Agriculture development support programme
PER	Protein Efficiency Ratio
PI	Profit Index
PPP	Projet Piscicole de Parakou
RF	River-flooded 'Whedos'
SDD	Secchi Disk Depth
SGR	Specific Growth Rate
SSA	Sub-Saharan Africa
TD	'Tschifi Dai'
TE	Total Expenditures
TH	Total Hardness
VC	Variable Costs
WHO	World Health Organisation



<u>CHAPTER I</u>

GENERAL INTRODUCTION

& STUDY SITE

1. PRESENT STATE OF THE WORLD FISHERY

Since 1973 the global demand for fish has doubled, with the developing world being responsible for 90 percent of this growth (DELGADO *et al.* 2003). In the same period the export of fish products, especially to developed countries, has become of vital importance to the economy of many developing countries. The value of such exports has increased from US$ 1.8 billion in 1976 to US$ 7.2 billion in 2006 and thus even surpasses the monetary value of many traditional agricultural export commodities such as cereals, sugar, coffee and tobacco (INTERNATIONAL TRADE CENTRE 2002; FAO 2009c).

In 1973, fish landings in developed countries still exceeded that of the developing countries by 6.6 million tons. However, this scenario changed and from 2003 to 2005 fish landings in developing countries exceeded that of the developed countries by 71.6 million tons (101.6 million to 30 million tons, respectively). In 2006, 79 percent of world fishery production occurred in developing countries and the traded fish accounted for 59 percent of the world export of fish and fishery products (FAO 2009c). The main reason for this shift is the overexploitation of the traditional marine capture fishery areas, especially since the late 1980s, in the developed world (DELGADO *et al.* 2003). As a consequence the developed countries are sending their modernised fleets to the more productive fishing areas of developing countries.

Even though capture fisheries showed an average annual growth rate of 1.2 percent, more detailed analysis indicated an increase in small pelagics and a decrease in demersal fishes caught (SHEHADEH & PEDINI 1997) highlighting the fact that we are fishing down the food web. The shift in species composition of the catch shows that the patterns of fishery management are not sustainable and will drastically alter the ecosystem as a consequence of severe changes of the food web dynamics (WILLIAMS 1996). But the fact that fish caught are often undersized meaning they don't reach sexual maturity and thus are not able to replenish their stocks is probably the most severe impacts on the future of the wild fish stocks (UEBERSCHAER 2009).

Fishery includes also the massive quantity of 'nontarget-species' known as 'bycatch' that can reach several times the amount of the target species landed. Global discarded 'bycatch' due to economical or regulatory reasons is estimated at over 20 million tons per year wasting almost one-quarter of the world fish catch (FAO 2000), with dolphins and turtles as most striking examples. Furthermore, bottom trawling and related activities destroy repeatedly large areas of the seafloor and remove benthic structure-forming fauna that leads to an alteration of the population dynamics of the seafloor habitat and thus the degradation of habitats for a wide range of organisms (DELGADO *et al.* 2003).

Consequently, marine and inland water fishery resources are strongly overexploited or are close to their maximum potential. According to the report of the FAO (2009c) approximately 28 percent of the natural fish stocks were overexploited, depleted or recovering from depletion, while further 52 percent were fully exploited and therefore are just producing catches that were at or close to their maximum sustainable limits. The rest of the stock, only about 20 percent were moderately or underexploited. As a result, global marine capture production of 81.9 million tons in 2006 was the third lowest since 1994 (FAO 2009c).

Despite the stagnation in capture fisheries, overall food fish production showed a growth rate of 3.1 percent per year from 1985 to 1997. But this is almost entirely the result of the boom in fish farming; with the majority of the net growth in aquaculture during the last 20 years has been produced in Asia, especially China (DELGADO *et al.* 2003). Therefore, in future the possibilities to expand fisheries production are greatest for those commodities that can be produced through fish farming and yields will probably increase through expanding the area under production as well as by increasing the yield per unit area through increased inputs or greater efficiency of inputs (FAO 2009c).

2 THE IMPORTANCE OF FISH AS PROTEIN SOURCE, ESPECIALLY IN AFRICA

Widespread hunger and malnutrition along with low and stagnating productivity in agriculture tend to be at the top of the list of food and agriculture concerns in developing countries. The number of people who do not have access to sufficient food to lead healthy and active lives increased from over 800 million in 2001 to 1.02 billion in 2009. In Sub-Saharan Africa (SSA) nearly 28 percent of children under the age of five are living below the minimum level of dietary energy consumption (PINSTRUP-ANDERSON & PANDYA-LORCH 2001; KAWARAZUKA 2010), and many hundreds of million are afflicted with deficiencies in micronutrients such as iodine, iron and vitamin A, which are required for normal growth and development and to prevent disabilities and premature death (PINSTRUP-ANDERSON & PANDYA-LORCH 2001). These deficiencies make people more prone to infectious illnesses and non-infectious diseases *e.g.* measles, malaria and diarrhoea (WHO/WFP/UNICEF 2006).

Poverty and malnutrition are not yet embanked, although farmers push forward to the boundaries of technology and ecology to produce more food. According to THE WORLD BANK (2010) in 2005 almost 73 percent of the population of SSA lived under the poverty line of US$ 2 per day. Additionally, global population is expected to double in the next 50 years, with at least 90 percent of this increase occurring in developing countries, many of which are already densely populated. SSA alone exhibits an annual population growth of 2.5 percent accounting for an additional 21 million people every year (THE WORLD BANK 2010a). An appropriate diet for the growing population would require a 50 percent increase of the recent food production (CGIAR & BMZ 2000). Since the global food supply presently is adequate to feed the world's population as a whole, most problems in food security are regional and will have to be addressed at the local level in the countries themselves (AIT 1994).

Fish, with the majority deriving from inland fisheries, is an important part of the daily diet and provides nearly one quarter of the world's supply of animal protein (Fig. 1).

In Africa 400 million people depend on fish for food security, providing more than 19 percent of the animal protein consumed (WorldFish Center 2010; FAO 2009c). Extensive river systems, *e.g.* the Rivers Congo and Niger and its floodplains, are widely accessible to poor households who would otherwise be without ready access to any source of animal protein (FAO 2009c).

Fish presents a crucial element in the diet of the population especially in countries where the staple plant crop is particularly low in protein – such as rice and maize.

The Republic of Benin belongs to the low-income food-deficit countries where a per capita consumption of 10.3 kg a year of fish accounts for 31.8 percent of animal protein in the diets of both rural and urban households (FAO 2009a, b). However, low income households spend more money on fish than other animal products because compared with meat it is relatively cheap (KAWARAZUKA 2010).

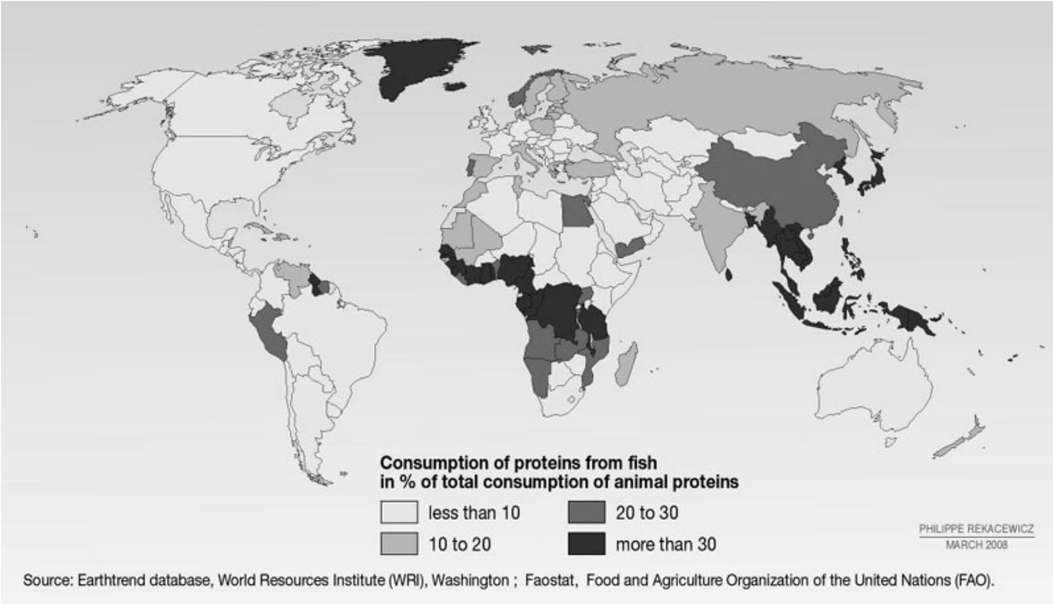


Fig. 1: Consumption of protein from fish and percentage of the total consumption of animal proteins. Source: http://www.worldfishcenter.org/wfcms/HQ/article.aspx?ID=808

Additionally, fish is high quality protein, rich in minerals and trace elements as well as Vitamins A and D that contributes to the improvement of the nutritional status (Fig. 2). Small fish, entirely consumed, with bones and organs is a particularly rich source of minerals and vitamins, thus contributing to nutrition security (THILSTED & ROOS 1999). Fatty fish is high in polyunsaturated fatty acids, especially omega 3, that are necessary for the proper development of the brain and body and additionally considered important in lowering the harmful blood cholesterol level (KAWARAZUKA 2010).

The contribution which fish can make to the nutritional status of young children and lactating women is particularly significant. Their protein requirements are much higher because protein is required for growth and lactating. For children, whose stomachs cannot digest the bulk of starchy staples, incorporation of small quantities of fish can substantially improve the biological value of the diet and contribute to significant improvements in the nutritional status (CAULFIELD *et al.* 1999; MUSKIET *et al*. 2006). Additionally, positive impacts of fish on reducing opportunistic infections and chronic wound healing processes of HIV infected people have been found (KAUNDA *et al.* 2008).

Despite the nutritional value of fish, per capita consumption in Sub-Saharan Africa is the world's lowest and decreased from 9.2 kg/capita/year in 1985 to 6.7 kg/capita/year in 1997 compared to the per capita consumption of 23.6 kg/year of the European Union in 1997. In spite of the enormous demographic growth within SSA, the total consumption of food fish stagnated at an annual of 3.7 million tons between 1987 and

1997 (DELGADO *et al.* 2003). The tremendously bad state of the marine and freshwater fishery and the increasing total demand for its products led to rising prices that particularly affect the poor. In some countries of SSA the average diet contained a smaller proportion of fish protein in the 1990s than during the 1970s. Besides, Africa is projected to need an additional 1.6 million tons of fish a year by 2015 just to maintain current consumption and projections of supply and demand to 2030 indicate that the gap will continue to grow, even though the quantity of fish landings can be maintained and aquaculture activities continue to progress (WORLDFISH CENTER 2010).

3. FISHERY – IMPORTANCE TO THE POPULATION AND THREATS TO ITS SUSTAINABILITY

Beside nutritive aspects, fisheries support the livelihood of millions of people by providing employment. Small-scale fisheries, also including river and floodplain fisheries, provide 95 percent of the employment within the fishery sector and represents two-thirds of the global fish catch (IFPRI 2008). The number of fishermen in Africa increased from 1,770,000 in 1990 to 3,529,000 in 2006 (FAO 2009c) but the fisheries are supported by up to 7.5 million people who supply materials *e.g.* nets and boats, as well as process and finally market the fish products, the latter employing particularly women (WORLDFISH CENTER 2010).

However, with regard to the marine fishery production the livelihood of the population dependent on fishing is threatened. Small-scale fishers, especially in West-Africa, are not able to compete with the highly subsidized fishing fleets of developed countries that are buying fishing rights belonging to countries such as Senegal and Guinea. Whilst the fees for the licenses only amount to a minor portion of the value of the catch, the industrial fishing fleet contributes to the overfishing of the coastal regions thus leading, in many regions, to the ruin of the local African fishing industry. The collapse of this important sector consequently drives many unemployed fishermen into the illegal migration to Europe. The increasing massive waves of emigrations arriving *e.g.* in Tenerife, is not by chance but the result of the social and economic misery experienced by the indigenous population depending on fishing as their main source of income (UEBERSCHAER 2009).

Regarding the inland fisheries, the situation is little better. In 2006, inland fisheries accounted for 11 percent (10 million tons) of the global capture fishery production (FAO 2009c). After Asia, Africa has the second highest inland fishery production (23.5 % of the world total) even though it showed a decrease of 2.7 percent in 2006. Whilst there are no industrial fishing fleets because the fish resources are not important enough, river and floodplain fisheries face growing pressure because of overfishing and inadequate land and water management.

The lack of integrated approaches to floodplain management and the lack of attention to the importance of the inland fishery in planning and development activities by the government, as well as developing aid programs, are major constraints to sustaining production (SVENDRUP-JENSEN 1999; LÄE *et al.* 2004). Moreover, the fast demographic growth not only results in higher demand for fish, and thus more intensive fishing activities, but also leads to higher demand for agricultural land and housing so further contributing to the degradation of floodplains.

All this is additionally worsened by the impact of climate change and the associated occurrence of severe droughts. Between 1969 and 1986 drought reduced the floodplain of the inner Niger delta in Mali from 20,000 km^2 to 5,000 km^2 resulting in a decrease of the fish production from 90,000 to 45,000 tons (LÄE *et al.* 2004).

Dam construction, *e.g.* the Markala and Selengue dams in Mali, are also responsible for a reduced flow and thus exacerbating the effects of the droughts. Furthermore, the floodplain area is shrinking, leading the reduction of territory used by riverine and floodplain dwelling fish for reproduction, feeding and spawning. As a result, the annual loss in total fish catches attributed to the two dams mentioned above has been estimated at 5,000 tons (LÄE 1992).

Consequently, the major source of income for fishers and other people integrated in the fishery sector is being reduced. As a result of the increasing effort required to catch one unit of fish, more and more fishers are forced to diversify their source of income. Therefore they abandon fishing as a professional full time job to become agro-fishermen, livestock breeders, or service providers. Other fishers staying in the industry respond to the overexploitation, or reduced landings, with an increased fishing effort by using, for example, smaller mesh nets or poisons, both of which are counterproductive to the fishery in the medium to long term.

With regard to the precarious state of the marine as well as the inland fisheries and its consequences for the population, aquaculture activities have to play an important role in increasing fish supply in the forthcoming decades and if conducted in a sustainable way, also in lowering the pressure on the natural fish stocks.

4. AQUACULTURE

4.1 Definition

Aquaculture is the aquatic equivalent of agriculture and animal husbandry and includes the production of both, animals (fish, crustacean, molluscs) and aquatic plants (*e.g.* algae). To distinguish aquaculture activities from those of capture fishery, the FAO definition (2010b) states that aquaculture implies some form of intervention in the rearing process that leads to increasing production such as regular stocking, or feeding, or protection from predators; and the organisms must also be harvested by an individual or corporate body, which has owned them throughout their rearing period.

Fish farming is just like any other farming, in general higher levels of inputs lead to higher output (Gietema 1993). Therefore, the most important difference between the production processes in aquaculture is the intensity of cultivation. In general, aquaculture may be divided in three different production types: 1) extensive systems with no intentional nutritional inputs; 2) semi-intensive systems with natural food production increased by fertilization and perhaps augmented by supplementary feeding with farm by-products; and 3) intensive systems which rely on nutritionally completed diets in dry pelleted form or fresh (AIT 1994).

4.2 History of Aquaculture

In Europe there are records of Romans already digging ponds for aquaculture. The first scientific experiments were made in Germany in 1934, but because of the World War II the results remained unutilized. After the war, when there was a serious protein shortage in European countries, large-scale experiments were initiated to determine optimal husbandry methods for raising ducks together with fish under the climatic conditions of Central Europe (Gietema 1993).

Inland aquaculture in most countries of the tropics is a relatively recent development and often started only a few decades ago (AIT 1994). In response to concerns following World War II about feeding an expanding population in developing countries, considerable research was carried out in tropical Africa and Asia in the 1950's and 1960's. The first research in Africa was reported from Kenya in 1924 (HUISMAN 1985), but in most of Sub-Saharan Africa aquaculture dates from the 1950s under the impetus of the various colonial administrations and the number of ponds increased rapidly. In general, from the 50s to the 80s aquaculture concentrated mainly on Tilapia culture. However a strong regression of the aquaculture activities were recorded from the 60s to the late 70s and (BRUMMETT & WILLIAMS 2000) after independence, aquaculture suffered a long period of decline since the newly independent governments didn't give a high priority to this sector and virtually all new activities were initiated by foreign donors. However, many observers of rural development held the opinion that aquaculture systems would not work in Africa, because in the 1990s the returns on government and international aquaculture investments appeared insignificant (FAO 2004). From the early 1970s to the early 1990s more than 300 assistance projects were initiated concentrating on extension, training and building state farms and hatcheries. However, these technologies were mostly imported from established industries without regard for the social and economic conditions. Therefore, in most countries of SSA aquaculture did not reach a commercial status and production technologies in the non-commercial sector have not changed noticeably (BRUMMETT & WILLIAMS 2000).

Shortcomings such as the lack of access to necessary inputs (fingerlings, feed, fertilizers etc.), bad technical support and low market prices of fish impeded the transition from non-commercial to commercial fish farming. Furthermore, intensive or high-cost production systems require the provision of nutritionally complete diets. The total feeding costs are high, restricting the fish production to fish with a high market value, which can be sold only as a luxury food or export commodity. Further constraints are the weak legislative and regulatory environments that do not support the development of fish farming particularly the severely limited access to credit because financial institutions are poorly informed about aquaculture (FAO 2006, 2009c).

Nevertheless, the non-commercial sector makes a significant contribution to the household or community livelihood (FAO 2006). In addition, the current situation the demand of which significantly outstrips the supply creates the market condition essential for the future development of aquaculture in Sub-Saharan Africa (FAO 2004). The contribution of aquaculture to the total fish intake doubled from 50 grams per person in 1984 to 100 grams per person in 1992 (FAO 1995). Whereas, in 2003 the SSA contribution of 72,334 tons to the African total was a mere 13.6 percent or 0.13 percent of the world total, production is estimated to increase to between 208,600 and 380,400 tons in 2013 (FAO 2006).

4.3 Aquaculture – Hope or Threat to Natural Resources?

In 1970 aquaculture only accounted for 6 percent of the global food fish supply whereas it increased to more than 47 percent in 2006 with a value of US$ 78.8 billion (FAO 2009c). From a production smaller than 1 million ton in the early 1950s, in 2006 production was recorded to be almost 52 million tons with China being by far the largest producer (Fig. 2). In fact, with an annual average growth rate of 6.9 percent from 1970 to 2006 aquaculture experienced the fastest growth within the world animal-food producing sectors (FAO 2009c).

With regard to developing countries, the fish supply from aquaculture rose from less than 2 million tons in 1973 to over 25 million tons in 1997. Thus, developing countries account for 90 percent of the global aquaculture production. But despite its high natural potential Africa contributes with 1.8 percent in 2008 only little to the global production (FAO 2010a). Nevertheless, the number of African fish farmers increased from 3000 in 1990 to 108,000 in 2006 (FAO 2009c).

But, connected to the boom of the global aquaculture production is the increasing demand for fish oil and fishmeal, both derived from wild fisheries, for incorporation into feeds for farmed fish. Approximately 30 percent of the total fish catch worldwide is reduced to fishmeal and from 4.5 millions tons in 1973 to 20.2 million tons in 2006 (Delgado *et al.* 2003; FAO 2009c). Consequently, concern is rising that the increasing demand for fish meal and fish oil will lead to greater fishing pressure on wild fish stocks.

Moreover, the increase of aquaculture production, especially shrimp farming, leads to the destruction of thousands of hectares of mangrove forests representing an important ecosystem and thus the habitat of numerous animal and plant species.

Aquaculture will also face competition for land and resource use from other activities. Pond aquaculture usually requires more water than most alternative agricultural production systems and thus will be even more in competition with the end-users (BOYD & GROSS 2000) that might result in conflicts.

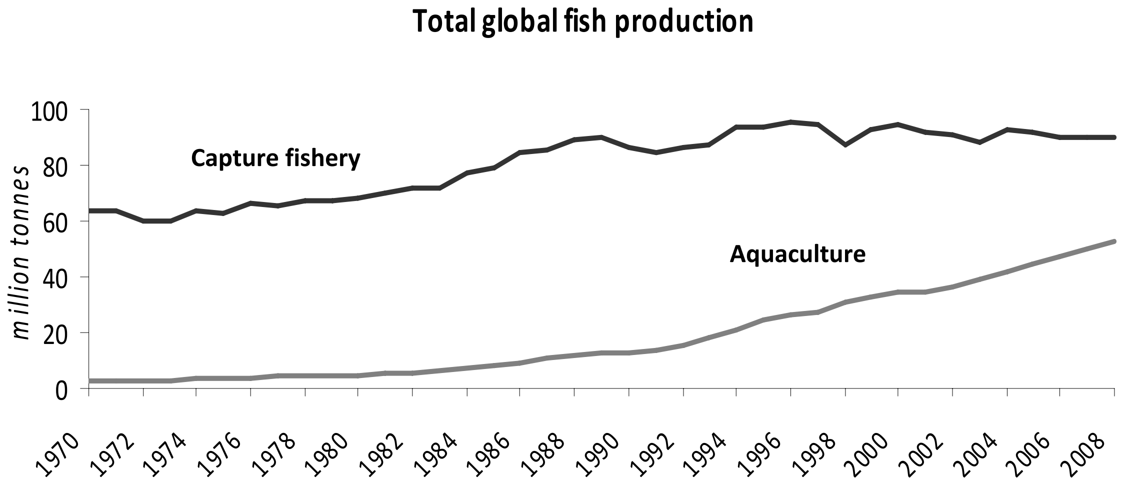


Fig. 2: Total capture and aquaculture fish production in million tons from 1970 to 2008. (Designed after the data recorded in fao.org – online query on fishery and aquaculture).

However, aquaculture was seen as a hope to release the pressure on natural fish stocks and aquatic resources, but this goal can only be achieved if it is conducted in a sustainable way. Therefore, it is important to concentrate all efforts in focusing aquaculture production on herbivorous or omnivorous fish species that are not necessarily depending on fish meal instead of carnivorous high-value fish species. The focus in aquaculture research should be aimed on the identification and utilization of plant protein sources not competing with human food resources to replace fish meal, either partially or totally. Although, in contrast to fish meal with its adequate protein quality and palatability (RUMSEY 1993), plant material may lead to lower growth performances, because of the presence of toxic substances or antinutrients, deficiency of essential amino acids (EAA) and poor digestibility, especially for carnivorous species, sources such as the protein-rich press cake of oil plants *e.g. Jatropha curcas* showed high potential for the use in aquafeed (HAUBER 2007). Moreover, in view of the competition for land it is essential to support and enhance extensive aquaculture systems, *e.g.* the 'Whedo'-aquaculture-system or rice-fish-farming, that is integrating different kinds of land use and that can be developed in areas not suitable for agricultural production.

Consequently, whether aquaculture will finally bring hope or threat to the ecosystem depends particularly on the future resource use *e.g.* land and source of aquafeed, but will be also strongly influenced by the population growth and the consumer buying habit.

4.4 What Kind of Aquaculture is Appropriate for Sub-Saharan Africa?

As already mentioned in the previous chapters there are numerous reasons working against intensive aquaculture systems in general, and it should be noted that its introduction and development in SSA turned out to be initially unsuccessful. All efforts to develop pond culture and other 'imported' production systems did not achieve any self-sustained development on a larger scale. One of many reasons for these failures has been the neglect of social and cultural aspects of inland fishery and aquaculture (GTZ 2002) as well as the insufficient regard for the indigenous knowledge base and natural resource constraints. Consequently, we have to think about more sustainable ways of adopting aquaculture in countries where it is not rooted in the cultural traditions because of its short history and new projects have to be based on participatory and evolutionary approaches (Brummett & Williams 2000).

In SSA, systems remaining in operation mostly use low levels of input, *e.g.* fertilization, and thus belong in the category of semi-intensive production. Due to the promotion of the primary food production there is no need of a nutritionally complete diet. The lack of nutrients in the supplementary feed will be compensated by natural food, which is suitable to the requirement of fish. These low-cost input systems are more appropriate to small-scale farmers because of following reasons listed below:

- Investment costs are quite low, mainly related to labour
- Low requirements for technological knowledge
- Fertilizer and feed inputs can be farm by-products
- Considering farmers with limited financial resources, the cost of purchasing off-farm fertilizers and supplementary feeds to intensify the system is cheaper than buying nutritionally complete feeds.
- The fish can be sold at a relatively cheap price and thereby be affordable to poor consumers which leads to an improvement in their diet as well as to an increased financial benefit to the farming household.

But even semi-intensive production systems might not be appropriate when adopted by people that are unfamiliar with this kind of technology. In this case rather than introducing a 'new' and unknown system, development intervention should address the complex inter-relationships between economic, social, and cultural determinants and traditional knowledge should be seen as a factor of production (GTZ 2002).

Therefore, the key to success is to build on already existing basic knowledge meaning that semi-intensive systems should be developed by modifying and improving traditional extensive systems, *e.g.* rice field/pond capture or the 'Whedo' and 'Acadja' systems. The acknowledgment of traditional resource management is an essential component of a more appropriate approach to aquaculture development. Thus, aquaculture development has to start, and should be further strengthened, from a local level in order to correspond with the traditions and needs of the population, thus laying the foundation for its acceptance and distribution.

4.5 Importance of Small-Scale Fish Farming

However, the most important requirements essential to enhance and build on traditional extensive systems is to gather basic knowledge on their functioning and management. Based on this knowledge combined with participatory research extensive systems can be successfully upgraded to semi-intensive fish farming systems. Under these prerequisites small-scale aquaculture will provide numerous advantages to their promoters and does also not necessarily lead to competition for land because it is often carried out on marginal land, such as swamps or flooded areas and even in roadside ditches, and therefore may also serve as an opportunity for landless farmers (WETCHAGARUN 1980).

In the best case, small-scale aquaculture will provide supplemental income for the farmers and in the worst case an additional subsistence income will be gained from consuming their own fish instead of having to buy them. Aquaculture will therefore help in improving diet with protein as well as vitamin and micro-nutrient supply especially in rural areas (THILSTED *et al.* 1997).

For small scale producers raising fish is suitable because of the relatively low input costs. The energy requirement to produce one gram of fish protein is 22-468 kJ compared with the requirement of 550-3,340 kJ/gram protein in land animals. Fish are good converters of low grade feed and agricultural wastes into high-value protein (KUMAR 1992).

Additionally, further employment opportunities might be created since the development of aquaculture activities are linked to labour demand in harvesting, processing, marketing and further to the establishment of hatcheries, nurseries, feed manufactories, etc. For example, the production of one ton of fish requires the labour of 2.5 persons representing an important source of indirect food security (KUMAR 1992).

Considering the consumers another advantage might be the declining market prices as a result of the augmented supply provided through aquaculture production. If harvesting of fish can coincident with the period of low fish supply due to the seasonality of fisheries, it could additionally prevent an increase in wild fish prices.

In this case not only the poorest will benefit from the more affordable fish, but low fish prices will probably also release the pressure on natural fish stock coming from great fishing fleets since in the long run industrial fishing will not be profitable anymore because of the high fixed costs (DELGADO *et al.* 2003).

In some countries, population growth is faster than the increase of food production. In Benin, to meet the national demand, the annual import of fish increased from 15,449 tons in 1999 to more than 54.500 tons in 2006 at a cost of 19.4 millions US$ (FAO 2008, 2010c). At the same time, inland water bodies, such as the Rivers Ouémé and Niger, were already over-fished or about to be over-fished in near future (GBAGUIDI & FIOGBE 1999; LAË *et al.* 2004). However, these imports must be paid for if they cannot be balanced by increased exports. Egypt, for example, imported 96,627 tons of fish in 1981 with a value of 96 million Euros to the expense of a weak economy. The subsequent introducing of fish farming by the government leaded to a higher level of national self-sufficiency and a decline of import costs by 63.9 percent (EL-BASIONY 1987). Nowadays Egypt provides almost half of the total reported production from African aquaculture (BRUMMETT & WILLIAMS 2000).

Summing up it can be recorded that small-scale aquaculture offers several advantages provided that this technology will be introduced in a way that takes also account of the cultural, social and economic aspects of the promoters and their traditional fishing activities.

5. CURRENT INFORMATION ON THE STUDY SITE

In a broader sense, my fieldwork took place in the Republic of Benin (06°25'-12°30' N, 0°-004°'45' E), West-Africa. The country was known as Dahomey during the colonial period and at independence. After the end of the self-proclaimed 'Marxist-Leninist' dictatorship in 1975, the country was renamed Benin because of the neutrality of the name (BUTLER 2006).

5.1 BENIN FISHERIES AND AQUACULTURE

Marine as well as inland fisheries play an important role in the country's economy. In 2006 the sector accounted for 3 percent of the gross domestic product, providing employment to approximately 211,300 men and women, and earning more than US$ 55 million in revenue. Additionally, the export of 342 tons of seafood earned approximately US$ 1.3 million (FAO 2008). High-value species such as shrimps and prawns are particularly exported to Europe, whereas fish are mainly smoked and exported to *e.g.* Niger and Nigeria (USAID WEST AFRICA 2008). By contrast, as already mentioned in the previous chapter, from 1999 to 2006 the annual import of fish increased more than three times to meet the national demand.

Nevertheless, the history of aquaculture in Benin is not inspiring. Most of the existing ponds that were built to introduce intensive aquaculture during the colonial period have been abandoned (FAO 1990). More recently in 1995, the West African Development Bank approved a loan to support the construction of a nursery as well as a feed factory aiming on the enhancement of the aquaculture sector, but unfortunately the project was not successful (TOKO 2007).

But despite the low acceptance of modern aquaculture that depends strongly on high quality inputs, a growing acceptance and implementation of the traditional extensive systems can be observed. Extensive aquaculture is basically related to the 'Acadja' and the 'Whedo' systems that are famous in the South of the country, whereas in the North people still rely particularly on the capture fishery in the River Niger

The 'Whedo'-aquaculture-system is especially well adopted in the Ouémé-Delta but its history is still not clear although one hypothesis is that they were already dug out by fishermen in medieval time (TOKO 2007). The system functions by the construction of artificial depression or pools within the floodplain. With the onset of the flood, migrating fish will leave the main river channel to spread on the plain. After the retreat of the flood water the fish get trapped in the 'Whedos' and subsequently harvested by the fishers. Usually these 'Whedos' take the form of channels with a width of 3 to 4m and often exceeding a kilometre in length. In Ouémé-Delta, 'Whedos' are particularly concentrated in low lying areas covering approximately 3 percent of the floodplain. This system can achieve high yields because it concentrates fish from a large floodplain area (WELCOMME 1975). Although, the 'Whedo'-aquaculture-system is fully integrated into the traditional life of the people of the southern Benin, it is a relatively new practice in the North of the country. Here, the first 'Whedos' were constructed in the 'Arrondissement' of Malanville in 1998; hence they differ significantly from the traditional ones in the Ouémé-Delta.

5.2 MALANVILLE

In order to investigate the recently introduced 'Whedo'-system in the North of Benin (West-Africa) my study took place in the Commune of Malanville (06°25'-12°30' N, 0°-004°'45' E). The commune with a dimension of 3,016 km² belongs to the department Alibori and is located in the North-east of the country (Fig.3) (PRODECOM 2006). But, the principal location and initial point of the major feeding trials was in the town Malanville itself (01°52.028' N, 003°23.54' E).

Malanville is the largest town of the department Alibori and is located at the border with the country of Niger and close to the border with Nigeria, thus representing an important point of cross-border trade and transit. Consequently, the town is a general hotspot in the North of Benin that attracts more and more people resulting in a rapid population growth rate, *e.g.* 4 percent in 2008. According to the census of 2008, the town is occupied by 44,000 registered inhabitants (PRODECOM 2006) with the majority belonging to the ethnic group of the Dendi. Further important ethnic groups are the Peulh, Mokollé, Djerma, Haoussa, Nago, Yoruba, Bariba, Mina, Adja, Goun, Fon and Kotocoli.

The region is located within the broad floodplain of the River Niger and the River Sota as well as some branches. Every year, the region is heavily exposed to major inundations of the River Niger covering an area of 275 km² at peak flood (WELCOMME 1985). Consequently, fishery is highly developed and is a traditional activity that takes place in the main rivers as well as in the floodplain and its pools and marshes. The fishery sector represents an important base of the regional economy.

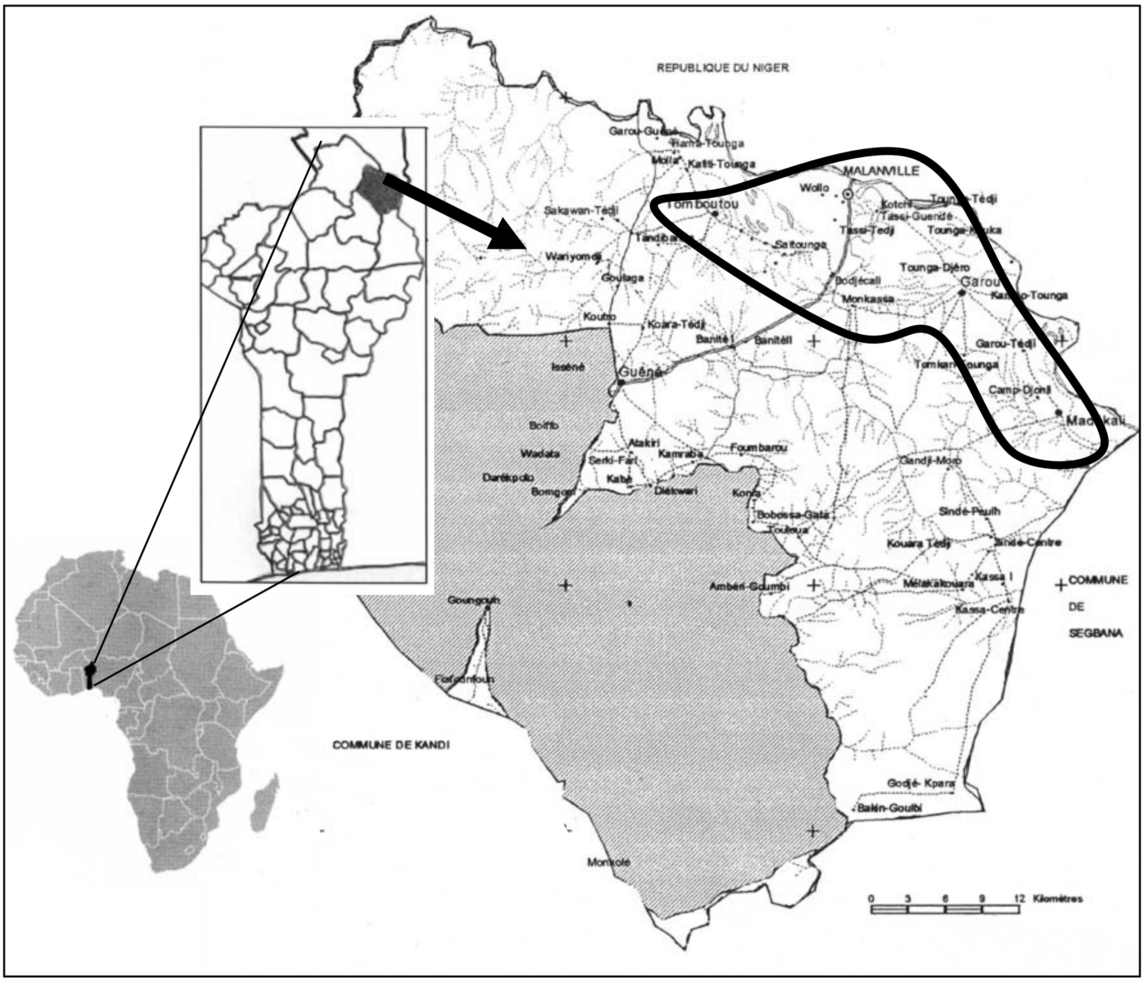


Fig. 3: Shown is the location of Benin in West-Africa, as well as the Commune of Malanville in the North-East of Benin and in detail. The mark in the north-eastern part of the Commune indicates the study area.

However, thanks to the geographical location of the region and its annual inundation, the first 'Whedos' were successfully introduced in 1998 to the small village of Kotchi, from where they spread fast to other low-lying floodplain areas along the main rivers. Because these fish holes were the focus of my study I concentrated further on the flood-affected 'Arrondissements' of Malanville, Toumboutou, Garou and Madekali. The remaining 'Arrondissement' of Guéné was neglected because it is not located in the floodplain, thus fishing is not an important source of income.

6. PERSPECTIVES AND OUTLINE OF THE THESIS

The thesis was announced with the title 'Improvement of the 'Whedo'-aquaculture-system in the North of Benin', and at this time no data were available on its development and management. Just of little help were the published data on the well described 'Whedos' in the Ouémé delta since these ponds are not comparable with those constructed in the North of Benin.

Consequently, my first aim was to gain basic knowledge on the 'Whedo'-system by considering its ecology as well as the environmental conditions. Both are important factors since they have an essential influence on the management of these artificial depressions and thus give important information on their potential for semi-intensive fish farming. Only a better knowledge on their ecological parameters allows to draw conclusions on water holding capacity, fish species appropriate for culturing, possible stocking density, rearing period, etc.

Accordingly, the following CHAPTER 2 – ECOLOGY OF THE 'WHEDO'-AQUACULTURE-SYSTEM - comprises:

- Information on the study side including factors such as land use system in the study region, the ecology of the floodplain and the role of fish for the indigenous population
- Information on the most important factors influencing the potential of the 'Tschifi dais' for semi-intensive fish farming *e.g.* soil properties, water quality, vegetation, seasonality etc.
- Fish diversity of the 'Tschifi dais' considering the different seasons as well as the different kinds of 'Whedos' depending on their location on the floodplain, the adaptations of the 'Whedo' dwelling fish species and potential factors determining the 'Whedos' fish diversity.

Results of this chapter are published or in preparation as:

HAUBER, M., BIERBACH, D. & LINSENMAIR, K. E. 2011. A description of teleost fish diversity in floodplain pools ('Whedos') and the Middle-Niger at Malanville (North-eastern Benin). Journal *of Applied Ichthyology* 27: 1-5.

HAUBER, M., BIERBACH, D. & LINSENMAIR, K. E. 2011 in press. New records of fish species in the River Niger at Malanville (North-East Benin). *Bulletin of Fish Biology*.

HAUBER, M., BIERBACH, D. & LINSENMAIR, K. E. accepted 2010. 'Whedos' - Permanent Floodplain pool and their potential for fish farming. FAO Technical Paper.

HAUBER, M., BIERBACH, D. & LINSENMAIR, K. E. in prep. The free-floating vegetation of permanent floodplain pools and the role of the water quality.

CHAPTER 3 – CURRENT MANAGEMENT OF THE 'WHEDO'-AQUACULTURE-SYSTEM - aims to provide a knowledge base on the existing traditional 'Whedo' management and to improve the understanding of the complexities of resource utilisation. In this context I attached great importance to address economic, social and cultural determinants as well as traditional knowledge that should be seen as a key factor of any successful intervention. Therefore, I attempted to investigate all factors involved within this sector by interviewing the owners and promoters of the 'Whedos', the consumer as well as the fishmongers. These results were completed by personal observation and participation. Hence, this chapter gives information on:

- The history and development of the 'Whedos' as well as the social structure of the promoters.
- The structural diversity of the ponds and insides on the most important features of the aquaculture practices.
- The traditional management strategies, the period and methods of the exploitation and additionally on the biomass harvested.
- The economic benefit and as well the marketing and processing of the fish.

Results of this chapter are published as:

HAUBER, M.E., BIERBACH, D. & LINSENMAIR, K.E.L. 2011. The Traditional 'Whedo' Aquaculture System in Northern Benin. *Journal of Applied Aquaculture* 23 (1): 67-84.

CHAPTER 4 - IMPROVEMENT OF THE PRODUCTIVITY OF THE 'WHEDO'-AQUACULTURE-SYSTEM- is based on the knowledge gained from the investigations described in CHAPTER 2 and CHAPTER 3 and aims at the improvement from an extensive 'Whedo'-aquaculture-system to a more productive semi-intensive one.

Accordingly, I decided that supplementary feeding of the most important fish species, *i.e. Clarias gariepinus*, is the best method to increase the overall productivity, primarily because the results showed that natural food supply is not sufficient and also because it is an interesting approach since it has not yet been investigated.

Therefore,

- Section 4.1 gives some basic information such as the biology, nutrient requirements and adaptation of the species *Clarias gariepinus* used for the different feeding trials

The next step was the identification of potential feed ingredients that are cost-efficient and locally available throughout the year. In this context I visited different markets, grain mills, slaughterhouses and bakeries to determine agricultural by-products and other potential waste products. Thus,

- Section 4.2 gives some basic definition on different kinds of fish feed, their main ingredients and mode of application in regard to the farming system, whereas
- Section 4.3 gives an overview on the potential materials identified, their prices and availability. Moreover, the chemical compositions of the most promising materials were analysed and presented in this section.

Finally I formulated different supplementary feeds and their performances were tested in two separated feeding trials in 2008 and 2009. Therefore,

- Section 4.4 presents the results of both feeding studies meaning the growth performance parameters of the fish fed with the different experimental diets as well as the benefit-cost analysis and the economical profitability of providing supplementary feed. The feed experiment in 2009 was based on the results obtained in 2008.

Results of this chapter are in preparation as:

HAUBER, M.E. & LINSENMAIR, K.E.L. Supplementary feeding of *Clarias gariepinus* (BURCHELL 1822) with locally available by-products in traditional floodplain pools in the North of Benin.

7. REFERENCES

AIT 1994. Partners in Development. The Promotion of Sustainable Aquaculture. Asian Institute of Technology, Bangkok, p. 98.

BOYD, C.E. & GROSS, A. 2000. Water use and conservation for inland aquaculture ponds. *Fishery Management and Ecology* 7: 55-63.

BRUMMETT, R.E. & WILLIAMS, M.J. 2000. The evolution of aquaculture in African rural and economic development. *Ecological Economics* 33: 193-200.

BUTLER, S. 2006. Benin: The Bradt Travel Guide, Bradt Publication, New York. p. 232.

CAULFIELD, L.E., HUFFMAN, S.L. & PIWOZ, E.G. 1999. Inventions to improve intake of complementary foods by infants 6 to 12 months of age in developing countries: impact on growth and on the prevalence of malnutrition and potential contribution to child survival. *Food and Nutrition Bulletin* 20 (2): 183-200.

CGIAR & BMZ 2000. Wege aus der Ernährungskrise. Forschen gegen den Hunger. Beratungsgruppe Entwicklungsorientierte Agrarforschung.

DELGADO, C. L., WADA. N., ROSEGRANT, M. W., MEIJER, S. & AHMED, M. 2003. Outlook for Fish to 2020 – Meeting global demand. International Food Policy Research Institute Washington D.C., USA and WorldFish Center Penang, Malaysia.

EL-BASIONY, E.-S. 1987. Entwicklungsmöglichkeiten der Fischwirtschaft in Ägypten, Eine empirische Analyse, Institute Für Agrarökonomie, Agrarwissenschaftlichen Fakultät der Christian-Albrechts-Universität zu Kiel, Diss., 1987, p. 203.

FAO (Food and Agriculture Organization of the United Nations).

_____ 1990. Source book for the inland fishery resources of Africa Vol. II, CIFA Technical Paper 18/2. FAO, Rome.

_____ 1995. Review of the state of the world fishery resources: Aquaculture. Fisheries Circular No. 866. FAO, Rome.

_____ 1999. Fish and fishery products: World apparent consumption statistics based on food balance sheets, LAURENTI, E. (ed.). Fisheries Circular No. 821 Revision 5. FAO, Rome.

_____ 2000. The state of World fisheries and aquaculture. FAO, Rome.

_____ 2004. Aquaculture Extension in Sub-Saharan Africa. Fisheries Circular No. 1002. FAO, Rome.

_____ 2006. Regional Review on Aquaculture development 4. Sub-Saharan Africa - 2005. Fisheries Circular No. 1017/4. FAO, Rome.

_____ 2008. Fishery and Aquaculture Country Profile – Benin. ftp://ftp.fao.org/FI/DOCUMENT/fcp/fr/FI_CP_BJ.pdf. Accessed December 2010.

______ 2009a. Calculated from food balance sheets. FAOSTAT Online request: http:faostat.fao.org/site/368/DesktopDefault.aspx?PageID=368#ancor. Accessed January 2010.

______ 2009b. Low-income food-deficit countries 2009. FAO country profiles. Online request: http://www.fao.org/countryprofiles/lifdc.asp. Accessed November 2010.

______ 2009c. The state of World fisheries and aquaculture. FAO, Rome.

______ 2010a. Fisheries and Aquaculture Information and Statistics Service, Statistical online query results: http://www.fao.org/figis/servlet/SQServlet?file=/usr/local/tomcat/FI/5.5.23/figis/webapps/figis/temp/hqp_49891.xml&outtype=html. Accessed December 2010.

______ 2010b. CWP Handbook of Fishery Statistical Standards, Section J: Definition of Aquaculture. http://www.fao.org/fishery/cwp/handbook/J/en. Accessed December 2010.

______ 2010c. Fishery Commodities Global Production and Trade (online query): FIGIS Fishery statistics, http://www.fao.org/fishery/statistics/global-commodities-production/query/en. Accessed December 2010.

GBAGUIDI A. & FIOGBE, E.D. 1999. Rapport national sur la pêche au Benin. COURS ACP-EU sur la gestion des pêches et de la biodiversité, Fish base ACP-EU Training, Dakar, Sénégal, du 12 au 23 avril 1999. http://www.fishbase.org/Training/CountryReports/Dakar/Benin.htm. Accessed December 2010.

GIETEMA, B. 1993. Fish Farming in Ponds in the Tropics - Book 1. Foundation for the Development of Agricultural Education and Training Wageningen, the Netherlands. STOAS.

GTZ 2002. Back to Basics. Traditional Inland Fisheries Management and Enhancement Systems in Sub-Saharan Africa and their Potential for Development. Universum Verlagsanstalt, Wiesbaden, Germany.

HAUBER, M. 2007. Growth performance of Nile tilapia (*Oreochromis niloticus* L.) fed diets containing detoxified *Jatropha curcas* seed kernel meal. Master thesis in agricultural sciences, Department of Aquaculture Systems and Animal Nutrition, University of Hohenheim, Germany.

HUISMAN, E.A. 1985. Aquaculture Research in the African Region. Pudoc, Wageningen.

IFPRI 2008. International Agricultural Research for Food Security, Poverty Reduction, and the Environment: What to Expect from Scaling Up CGIAR Investments and 'Best Bet' Programs; IFPRI.

INTERNATIONAL TRADE CENTRE 2002. ITC Databases: Aggregated Trade Statistics. http://www.intracen.org/tradstat/welcome.htm. Accessed November 2002.

KAUNDA, W., CHIZYUKA M. & PHIRI, M. 2008. The possible role of medicinal mushrooms and Kapenta wound healing: A preliminary Zambian Study. Project report, Kenneth Kaunda Children of Africa Foundation (KKCAF). Lusaka, Zambia.

KAWARAZUKA, N. 2010. The contribution of fish intake, aquaculture, and small-scale fisheries to improving nutrition: A literature review. The WorldFish Center Working Paper No. 2106. Penang, Malaysia. p. 51.

KUMAR, D. 1992. Fish Culture in undrainable Ponds. Fisheries Technical Paper Nº 325. FAO, Rom.

LAË R. 1992. Influence de l'hydrologie sur l'évolution des pêcheries du Delta central du Niger der 1966 à 1989*. Journal of Aquatic Living Resources* 5 (2): 115-126.

LAË R., WILLIAMS S., MASSOU, A.M., MORAND P. & MIKOLASEK O. 2004. Review of the present state of the environment, fish stocks and fisheries of the River Niger (West Africa). Pp. 199-277 *In* WELCOMME R. & PETR T. (eds.). Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries: Sustaining livelihoods and biodiversity in the new millennium. Vol. I., Rome: FAO, International symposium on the management of large river for fisheries 2, 2003-02-11/2003-02-14, Phnom Penh, Cambodia.

MUSKIET, F.A., VAN GOOR, S.A., KUIPERS, R.S., VELZING-AARTS, F.V., SMIT, E.N., BOUWSTRA, H., DIJCK-BROUWER, D.A., BOERSMA, E.R. & ADDERS-ALGA, M., 2006. Long-chain polyunsaturated fatty acids in maternal and infant nutrition. *Prostaglandins Leukot Essent Fatty Acids* 75: 135-144.

PINSTRUP-ANDERSON, P. & PANDYA-LORCH, R. 2001. Emerging Food and Agriculture Concerns in the Developing World. Entwicklung ländlicher Raum - Beiträge zur Internationalen Zusammenarbeit 4: 28-30.

PRODECOM 2006. Schéma directeur d'aménagement de la commune de Malanville: analyse et diagnostic. SERHAUS-SA, Cotonou-Bénin. p. 23.

RUMSEY, G. L. 1993. Fish meal and alternative sources of protein. *Fisheries* 18: 14-19.

SHEHADEH. Z. H. & PEDINI, M. 1997. Issues and challenges. In: Review of the state of world aquaculture. Inland Water Resources and Aquaculture Service, Fishery Resources Division**.** FAO Fisheries Circular No. 886, Rev.1. FAO, Rome.

SVENDRUP-JENSEN, S. 1999. Conference International Consultation on Fisheries Policy Research in Developing Countries, 3-5 June 1997. Hirtshals, Denmark.
THE WORLD BANK 2010. http://search.worldbank.org/data?qterm=poverty+line+sub+saharan+Africa&language=EN&format=html. Accessed December 2010.

THE WORLD BANK 2010a. Data and Statistics in Africa.

http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/AFRICAEXT/EXTPUBREP/EXTSTATINAFR/0,,menuPK:824057~pagePK:64168427~piPK:64168435~theSitePK:824043,00.html. Accessed December 2010.

THILSTED, S.H., ROOS, N. & HASSAN, N. 1997. The role of small indigenous fish species in food and nutrition security in Bangladesh. Naga – The ICLARM Quarterly (supplement). July-December: 13-15.

THILSTED, S.H. & ROOS, N. 1999. Policy issues on fisheries in relation to food and nutrition security. Pp. 61-69 *In* AHMEND, M., DELGADO, C., SVERDRUP-JENSEN & SANTOS, R. (eds.). Fisheries policy research in developing countries: issues, priorities and needs. International Center for Living Aquatic Resource Management. Makali City, Philippines.

TOKO, I. 2007. Amélioration de la production halieutique des trous traditionnels à poissons ('Whedos') du delta de l'Ouémé (sud Bénin) par la promotion de l'élevage des poissons-chats *Clarias gariepinus* et *Heterobranchus longifilis.* Dissertation aux facultés des sciences, département de biologie; Facultés Universitaires Notre-Dame de la Paix, Namur, Belgique.

UEBERSCHAER, B. 2009. Fish consumption in accordance with ecological status. Rural 21 - *The International Journal for Rural Development* 43 (2): 36-38.

USAID WEST AFRICA 2008. West Africa Fisheries Profiles – Benin:
http://www.imcsnet.org/imcs/docs/benin_fishery_profile_apr08.pdf.
Accessed December 2010

WELCOMME, R. L. 1975. Extensive aquaculture practices on African floodplains. *In* Supplement 1 to the Report of the Symposium on aquaculture in Africa. CIFA Technical Paper No. 4 (Supplement 1). 30.09.-2.10.1975 in Accra, Ghana. FAO, Rome. p. 791.

WELCOMME, R.L. 1985. River fisheries. FAO Fisheries Technical Paper 262, Rome.

WETCHAGARUN, K. 1980. Integrated Agriculture-Aquaculture Farming Study in Thailand with Case Study on Chicken-Fish Farming. Pp. 243-248 *In* PULLIN, R.S.V. & SHEHADEH Z.H. (eds.). Integrated agriculture-aquaculture farming systems. ICLARM Conference Proceedings 4, WorldFish Center Penang, Malaysia.

WHO/WFP/UNICEF 2006. Preventing and controlling micronutrient deficiencies in populations affected by an emergency. Geneva: Joint statement by the World Health Organizations, the World Food Programme and the United Children's Fund.

WILLIAMS, M.J. 1996. Transition in the contribution of living aquatic resources to sustainable food security. *In* DE SILVA SENA S. (ed.). Perspectives in Asian fisheries. Makati City, the Philippines: Asian Fishery Society.

WORLDFISH CENTER 2010. Fish supply and Food Security for Africa.
http://www.worldfishcenter.org/resource_centre/Fish%20Supply%20and%20Food%20Security%20for%20Africa.pdf. Accessed November 2010.

<u>CHAPTER II</u>

ECOLOGY OF THE 'WHEDO'-AQUACULTURE-SYSTEM

1. INTRODUCTION

1.1 Notes on the Study Area and the Rivers Niger and Sota

1.1.1 Climate

Within this study, we concentrated on the environs of the frontier town Malanville (North-Benin) located at 11°52.028' latitude and 3°23.548' longitude (GPS data collected at the main market) with an average altitude of 200 m above sea level. The town is situated on the border to neighbouring Niger along the Middle-Niger River, 1,130 km upstream of the estuary, and 3,050 km downstream from its source (Moritz *et al.* 2006). Table 1 and Figure 1 summarise the measurements of precipitation, temperature as well as radiation from 1961 – 2000.

The region belongs to the Sudanian-Sahelian or semi-arid tropical climate with two distinct seasons. The wet season starts with the first rain in May and usually lasts until October, whereas the pronounced dry season prevails for the rest of the year. Around December/January the Harmattan, a dry dust-carrying wind from the Sahara, reaches the region. This desert wind lasts for approximately two or three months causing a drop of the mean temperature to about 26° C (Tab.1). The mean annual precipitation measured from 1985 to 2006 was 819 mm with an average of 51 rainy days per year (unpublished data from the local fishery authority). The strongest insolation was reported in February with 9.6 hours/day, whereas lowest values were registered in August (6.24 hours/day) combined with the highest monthly precipitation rate (Dossou 2008).

Tab. 1: Temperature and Rainfall for the study area.

		J	F	M	A	M	J	J	A	S	O	N	D
* Temp (°C)	Mean max.	33	36	39	40	38	35	32	31	32	36	36	33
	Mean	26	29	32	34	32	30	27	27	27	29	28	26
	Mean min.	19	22	25	27	26	24	23	22	22	23	21	19
**Rain (mm)	Max	0	0	0	70	144	152	268	317	232	89	0	0
	Mean	0	0	0	22	79	106	203	233	171	46	0	0
	Min.	0	0	0	5	42	25	122	138	96	6	0	0
**Rainy days	Mean	0	0	0	2	6	7	12	16	10	3	0	0
* Wind speed (m/sec)	Mean	3.1	3	2.6	2.3	2.3	2.1	1.6	1.3	1.2	1.3	2	2.7

* Data measured at the meteorological station in Gaya, Niger (ca. 13 km from Malanville) from 1961-1990.
**Data measured by the Fishery authority of Malanville from 1997-2006.

1.1.2 Hydrology

With a length of 4,183 km, the Niger is the largest river in West-Africa and classified as a Sudanian River because it drains the arid Sahelian savannah (LAË *et al.* 2004). The river rises in a relatively wet area, the Fouta Djallon Mountains of Sierra Leone and Guinea and flows through different climatic zones until it discharges into the gulf of Guinea in Nigeria forming a big estuary. For Benin the Niger River constitutes the 140 km north-eastern frontier with Niger (FROESE & PAULY 2009) and covers an area of 44,000 km² at peak flood and 32 km² at low water (RAMSAR 2010).

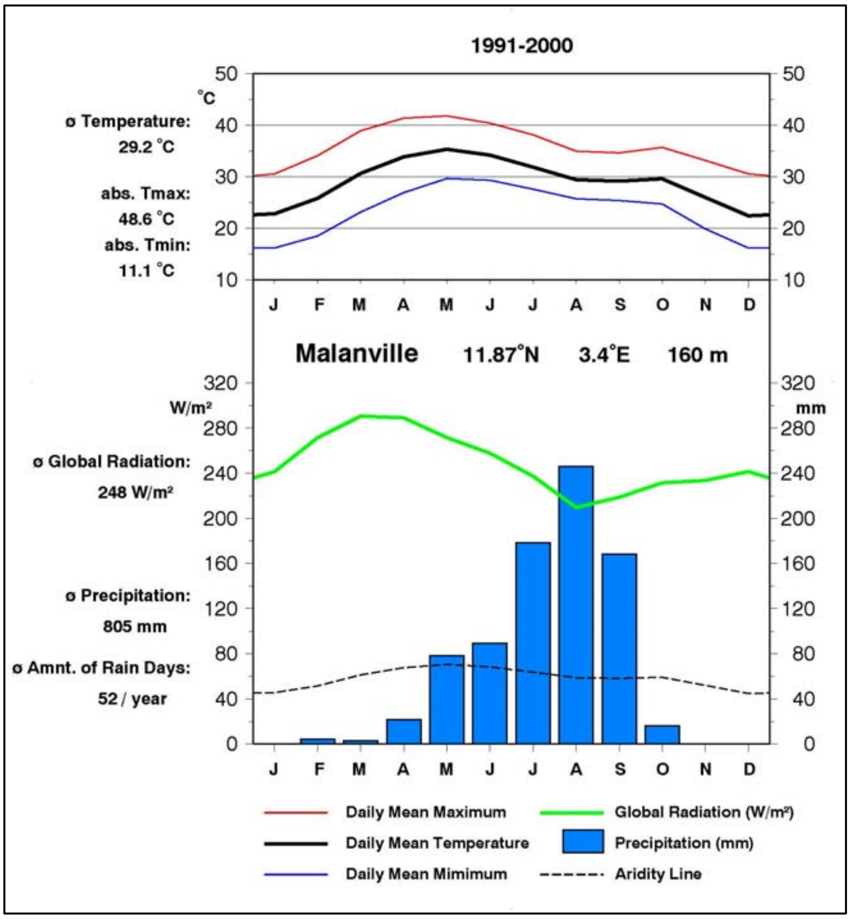


Fig. 1: Data on temperature, radiation and precipitation of Malanville for the years 1991 to 2000. Source: PAETH *et al.* 2005, http://www.impetus.uni-koeln.de/fileadmin/content/daten/remo_diagramme/dateien/D002_9100_en.pdf.

The river Sota is a tributary with a length of 250 km and a drainage area of 13,410 km² flowing into the Middle-Niger at Malanville (AGOSSOU 2001; VAN DEN BOSSCHE & BERNACSEK 1990).

The region is characterized by two different floods. The first flood occurs in August/September as a result of the intense local precipitation and drainage of local rivers (the Sota, Alibori and Mekrou). As a result of the high silt content the water is milky and has a lutescent colour. Therefore, this first flood is called Hari Kouarè (*Dendi* white water) by the local population. The second flood occurs in November/December from the raised level of the River Niger. This water is comparatively clean when it reaches the commune of Malanville and for this reason it is known as Hari Bi (*Dendi* black water). According to WELCOMME (1979), the flood crest takes more than 100 days to move 1,160 km from the headwaters near Koulikoro (Mali) to Malanville and therefore arrives during the dry season, after the Hari Kouarè.

In general, the intensities of the two floods within one year are of equal average value (2,200 m^3s^{-1}), but this varies from year to year depending on the rainfall as well as on the water levels of the reservoirs upstream *i.e.* Lake Selengue and Lake Markala (Mali) and the Kandaji dam (Niger) (ANDERSEN *et al.* 2006; LAË *et al.* 2004). Apart from January the water level drops progressively and usually in June the river reaches its lowest level, uncovering the rocky river bed.

1.1.3 LAND USE

Until 1950 Malanville (Fig. 2) was just a small village inhabited by not more than 400 to 500 hundred fishermen and their families. But the town has grown and today covers an area of 3,016 m^2. In 2005 population reached already 38,600 people (ADJOVI 2006) with a total of about 95,145 habitants living in the commune (unpublished data of the census in 2006). According to the projections of the World Gazetteer Malanville's population will have increased to 42,543 inhabitants in 2010 (THE WORLD GAZETTEER 2010).

Generally, Benin is an agricultural country (CIFA 1990) and in the local community, as well as in the city of Malanville agriculture represents the basis of the economy. With regard to the 95,145 inhabitants of the commune (40,543 men and 48,300 women) 86 percent worked in the agricultural sector (PRODECOM 2006). The absence of an industrial sector and the lack of employment opportunities further contribute to the dependency of the population on agricultural production.

The most important agricultural products grown for subsistence are sorghum (6,800 ha), millet (5,100 ha) and local maize (4,400 ha). Other important plant products (partly cash crops) are cotton (> 8,000 ha), rice, ground nuts, cassava, sweet potatoes and potatoes. Farming is carried out with family labour and is usually done by hand using locally forged hoes. Fertilizers and insecticides are particularly applied to rice and cotton.

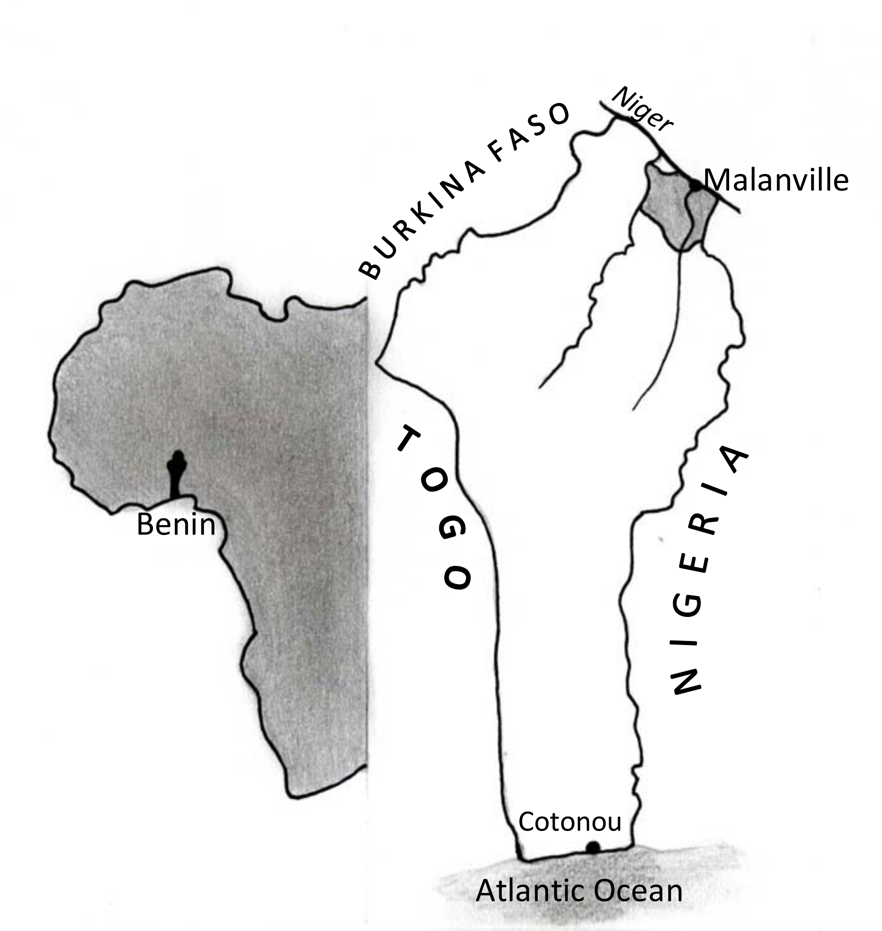


Fig. 2: Map of Africa with Benin stressed in darker colour and map of Benin. The commune and the city of Malanville are indicated by the dark colour in the North-East of the country.

However, around the city Malanville the land use differs since there is only a negligible cotton production whereas rice can be seen as most important cash crop. Rice cultivation is quite intensive and a huge area with a complex irrigation system (further referred to as 'rice perimeter') along the Niger River was made accessible to support its cultivation further. Generally, rice production is subsidized by the government and not only the 'rice perimeter' but also the donation of mills and motor pumps by the central government has contributed to the further development of this sector. A major part of the local production is transported by the government and directly traded in the capital.

The local rice cultivation system can be divided according to the cropping system. On one hand rice is cultivated more intensively within the 'rice perimeter' of Malanville. The perimeter covers approximately 516 ha, whereas about 180 ha are recently developed and accessible through an extensive irrigation system. Thus, rice is cultivated all year round in two to three production cycles. Recently, a Chinese development project makes another 210 ha accessible within the perimeter for future rice cultivation. Nowadays, approximately 27.3 percent of the active townspeople are working within this sector (ADJOVI 2006). On the other hand, in regions without controlled irrigation systems, *e.g.* in Bodjekali or Monkassa, rice is planted synchronously with the flood of the rivers or the rainy season, respectively. The region is also famous for its significant vegetable production particularly onions, piment, okra and tomatoes, which are distributed and traded in the whole country. Apart from this, mangoes are grown in huge orchards near the villages.

Livestock husbandry is also quite significant, especially with regard to the animal-herding nomads (Peulh/Fulani) who can gain access to water and pastures made available by the annual flood. The most important animals are cattle and they are especially abundant on the floodplain of the Niger.

Besides agriculture, fishery is an important sector and a traditional activity in the region mainly conducted within the main rivers (Niger, Sota, Alibori as well as their branches) and their vast floodplains. The intensity of fishing varies with the cycles of the water level.

Fish landings are high with the retreat of the flood because fish are forced to migrate from the floodplain back to the main river channel, where they were intensively fished by the installation of nets and barriers in the different channels and passages still connected with the river (personal observation and communication with the director of the fishery authority). Fishery is also quite intensive at the beginning of the dry season, when the fish are confined to swamps, pools and the river channel and thus easier to catch. But towards the end of the dry season catches in these water bodies decline as a consequence of intensive fishing activity leading to overexploitation.

Fish landings increase again with the beginning of the flood when fish are migrating up-river to breed. In this period fishing activity focuses on breeding fish thus potentially harming natural fish stocks more than by catching remaining fish left in pools when the water recedes (WELCOMME 1975). Generally, the timing of different cultivation and fishing practices are in accordance with the annual flood cycle or the local rainfalls, respectively (Fig. 3).

However, since 1998 the operation of fish holes was introduced by the director of the local fishery authority. Until this time, this in the South of Benin traditional fishery system was not know in the commune of Malanville; but nevertheless gained wide acceptance especially by the rural population.

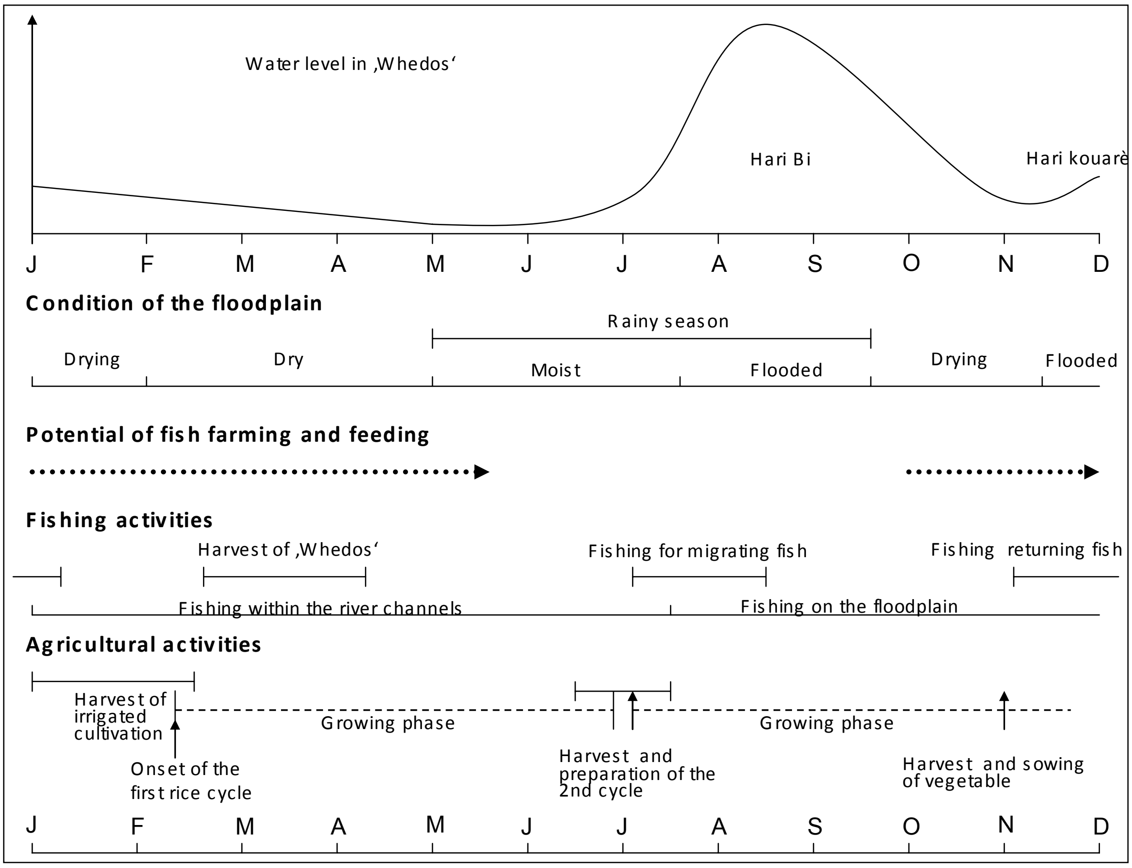


Fig. 3: Annual flooding cycle and seasonal use of the floodplain in the commune of Malanville (*modified from* W*ELCOMME* *1975*).

The operated fish holes in the Ouémé Delta were called 'Whedos', whereas the indigenous population of the commune Malanville gave them the name 'Tschifi dai' (*Dendi* fish hole). The management of the 'Tschifi dais' ranges from farmers that are feeding, stocking and maintaining their holes regularly to farmers that are abandoning them for the whole year except of the annual harvest. This extensive system developed to a 'blue revolution' and within the last decade more than 460 fish holes were newly constructed by the indigenous population.

2. IMPORTANCE OF THE RIVER AND ITS FLOODPLAIN IN THE STUDY REGION

In general, floodplains are defined as low lying areas along rivers that are seasonally inundated by the overspill from the main river channel. Within the floodplain swamps and pools are situated within depressions that can be permanently but can also temporarily desiccate during the dry season. In Benin, the Niger at peak flood covers an area of 274 km² forming a fringing floodplain (WELCOMME 1985) including swamps and pools. Local rainfall and overspill from tributaries inundates the floodplain and connects it with the main Niger River even before it overflows its banks.

The Niger and its tributaries play important roles in the life of the almost two million people living in the Niger Basin in Benin (ANDERSEN *et al.* 2005) providing essential water resources for agriculture, fisheries, livestock and wildlife (LAË *et al.* 2004).

Agricultural practices within the floodplain are in tune with the annual flood cycle and especially the cultivation of rice in the commune of Malanville depends highly on the intensity of the flood. In 1998, farmers started to construct artificial pools, 'Tschifi dais', within the floodplain to trap migrating fish that will remain in the holes when the flood withdraws. Stocking density, meaning the quantity of migrating fish caught, and thus productivity highly depends on the location within the floodplain as well as the intensity and duration of the flood.

In addition to agricultural products, clay and plant biomass for roof and house construction (*e.g. Typha* sp. and *Cyperus* spp.) also play a very important role for the rural population. After the flood there is a buzz of activity in forming bricks out of the new alluvial mud. The depressions within the floodplain resulting from the digging of clay might be one explanation for the development of the first fish holes (Fig. 4).

The Niger River still has an important role as a route for transportation and trade with agricultural products especially with the neighbouring countries Niger and Nigeria. Huge amounts of vegetables and cereals are imported from Nigeria, whereas smoked fish and frogs are transported in huge amounts from Benin to Nigeria.

Wetlands are invaluable habitats for wild animals *e.g.* amphibians (frogs and toads), reptiles (crocodiles, turtles *etc.*), birds and mammals (Hippopotami) but also necessary for domestic animals by providing water and important grazing areas during periods when the surrounding land is dry (THOMPSON & POLET 2000).

Regarding the ecological function, floodplains are essential spawning habitats for the majority of economically important fish species (WELCOMME 1975, 1979).

Flooding appears to be essential to the completion of the reproductive cycle of most species and the failure of the floods, *e.g.* as result of the Sahelian drought, lead to reduced reproduction success of fish.

Generally, many functions of the biology of fish living in floodplain systems vary with the hydrological cycle. The intensity of the flood has an impact on reproduction, growth, feeding and survival of fish (WELCOMME 1975, 2003) and thus on the quantity of fish landings and the closely coupled income of the fishermen. In the 1950s some river catches were still correlated with the flood regime from 4 to 5 years earlier, thus indicating that the fishery targeted older and bigger fish, but in recent years catches are directly correlated with the flood of the same year showing that catches mainly consist of young-of-the-year fish and thus indicating the increasing pressure on natural stocks (ALLAN *et al.* 2005; WELCOMME 1979, 2003; LAË 1992, 1995).

Fig. 4: Fabrication of bricks and the development of a new fish hole

3. IMPORTANCE OF FISH FOR THE POPULATION OF MALANVILLE

In 1910, the most important settlement in the region was Bodjekali (7 km from Malanville) only consisting of some huts of fishermen. Later 'Tassi' (*Dendi* sand), since 1949 renamed in Malanville, was created on the floodplain with the arrival of new inhabitants. Historically, fishing always played an important role and represents a traditional activity for the rural population (ADJOVI 2006; PRODECOM 2006). Up to the present, the fishery sector is of high importance to the local economy and especially to the poor quarters of Malanville, *e.g.* Wollo and the small villages of the commune, where an important part of the inhabitants depend on the income from their daily fish landings. However, with the recent goal of the government – the expansion of the rice cultivation sector- parcels of land were given to the landless population of Malanville, thus many fishermen are changing their profession to become rice cultivators. But this development only seems to be successful as long as the market prices for rice remain preferable which is currently only guaranteed through governmental subventions.

Nevertheless, Malanville is famous for its impressive supply of fish throughout the country; travellers and visitors are always eager to visit the local fish market. The diverse production and sales sectors provide many job opportunities and involve different sections of the population, particularly in rural areas where job opportunities are scarce.

Whereas fishing is exclusively the work of men, women play an important role in processing and marketing of the fish. Usually, the women have informal contracts with specific fishermen and they are thus waiting for them each day at the river bank to buy their landings. The fish are brought to the market where it is sold fresh, smoked or fried; other women will buy the fish to prepare and sell for consumption on the street.

In view to the protein poor nutrition in developing countries, mainly based on high carbohydrate products, fish is an important source of animal protein, particularly for the poor since its market price is comparatively low relative to meat products. The Republic of Benin belongs to the low-income food-deficit countries where a per capita consumption of 10.3 kg a year of fish accounts for 31.8 percent of animal protein in the diets of both, rural and urban, households (FAO 2009a, b). According to BREUIL & QUENSIÈRE (1995 cited in LAË *et al.* 2005) fish consumption in 1995 was about 10.5 kg/capita/year compared to 7.8 kg/capita/year of consumed meat in the Central Delta of the Niger. In 2009, mean market prices on the main market in Malanville were 2,000 FCFA and 1,833 FCFA for beef/sheep and goat meat, respectively, whereas the mean prices for 1 kg of fresh *Clarias* spp. was 1,019 FCFA.

Since 1998 fish were not anymore only supplied from traditional fishery but increasingly also from fish draped and caught in 'Tschifi dais' which is a result of the decreasing incomes from fishery forcing the fishermen to diversify their sources of income. Additionally, climatic factors such as longer dry seasons and heavy local rains have provided a strong incentive to local farmers to start the business of fish holes in the floodplains of the main rivers (Niger, Sota, Alibori and its branches).

The fast increase in the number of fish holes during the last decade highlights their broad acceptance and benefit to the population. The construction of new fish holes still goes on mostly without any external impulse by development aid projects or other financial support.

4. THREATS TO THE RIVER ECOSYSTEM

Ninety-eight fish species belonging to 22 families have been recorded from the Middle Niger River of which 83 are of economical importance. All these species are well adapted to the seasonal and year to year variations of the hydrology. However, as a consequence of the changes that have happened to the river habitat in the last decades, the population structure of the fish has changed (LAË *et al.* 2005). In the reach of the Niger River at Malanville species like *Parachanna obscura* and *Gymnarchus niloticus* have disappeared from the catches whereas the proportion of *Clarias* spp. and *Tilapia* spp. have increased (personal communication). Moreover, the abundance of large-sized species, *e.g. Lates niloticus,* has gradually been replaced by small-sized and more productive species a consequence of increasing fishing effort and the so called fishing down the food web (ALLAN *et al.* 2005).

In the central delta, fish landings have declined significantly from 90,000 metric tonnes in 1968 to 45,000 tonnes in 1989 (LAË *et al.* 2004). Observations at Malanville gave serious cause for concern since the decline in fish recruitment as a consequence of drought combined with intensive fishing effort lead to a reduction of the length of the fish caught (COENEN 1986 and own observation). Several indices, such as the reduction of the total catch, decreasing average size of caught fish, juveniles forming the major part of fish landings as well as changing fish communities with the disappearance of some species, indicate that natural stocks are under high pressure.

Population growth in the basin is one of the reasons why the fish stocks are under growing pressure. The population of Malanville grew by approximately 4.8 percent from 1992 to 2000 (ADJOVI 2006), leading not only to a higher demand for fish and thus more intensive fishing activities, but also to the degradation of important floodplain areas due to expansion of agriculture and house construction. Similarly, in Nigeria, the number of fishermen in the Niger Delta increased from 466,602 in 1991 to 1,177,308 in 2001. Habitats are also becoming degraded due to human activities *e.g.* by cutting of wood and over-grazing, that lead to erosion and thus higher silt loadings and therefore the formation of sandbanks. Consequently, spawning habitats are destroyed, water volume is reduced and water quality deteriorates by increasing turbidity and declining concentrations of dissolved oxygen (LAË *et al.* 2004).

The construction of dams and barrages upstream from floodplains represents another threat to fish populations since inundated areas used for reproduction are lost, thus leading to reduced fish catches as well as changes in the composition of species assemblages. Dams have a negative impact on the natural dynamic of rivers, on fish abundance and diversity by disturbing migration patterns as well as by increasing the impact of drought by further lowering the already reduced flood flows (PAINE 1986). This was so for example after the construction of the Kainji Dam in Nigeria (FAO 1972 cited in WELCOMME 1975; SAGUA 1978). Also, the Markala dam in Mali constructed for gravity irrigation interrupts the passage of many species from the Central Delta to the reaches upstream the dam (WELCOMME 1975). Upstream of Malanville is the hydroelectric dam in Selengue on the Sankarani River (Mali) which forms Lake Selengue, and there is another dam in Niger at Kandaji. The annual loss of fish catches for the Central Delta as a consequence of dam construction was estimated to be 5,000 tonnes (LAË *et al.* 2004).

Furthermore, pollution of rivers tends to increase with population growth. At Malanville pollution is mainly generated by domestic waste and sewage from riparian settlements whereas pollution from industry does not constitute a problem.

Considering the nine Niger River Basin countries, Benin is classified as a water producing country. From Niamey to Malanville the Niger gains about 20 percent of its flow from the Beninese right bank tributaries the Sota, the Alibori, and the Mekrou (ANDERSEN *et al.* 2006). Nevertheless, the Sahelian drought in the 1970s, lead to shorter rainy seasons and a significant decrease in the amount of annual rainfall (LAË *et al.* 2004). According to ANDERSEN *et al.* (2005) reduction of precipitation by 10-30 percent leads to a deficit of 20-60 percent in the river discharges, thus leading to severe decline of the water level that was demonstrated by the drying-out of the Niger at Niamey in 1985 as a consequence of the Sahelian drought. Additionally, before 1960 the average flow at Malanville was 1140 cubic meters per second, but between 1980 and 2004 it declined to 800 cubic meters per second; also because of the increased demand for water for irrigation purposes. Consequently, floodplain areas are significantly reduced and spawning and feeding habitats of fish disappeared or are fragmented (LAË *et al.* 2004).

Finally, one reason and also consequence of reduced fish landings is the use of destructive fishing gears. Historically, the pressure on natural fish stocks in the Niger increased significantly due to the introduction of synthetic nets and the absence of governmental control over fishing activities. Also the mesh size of the nets declined from 50 mm before 1975 to 24 to 35 mm in 2004 (LAË *et al.* 2004). However, local fishermen at Malanville use a multitude of different fishing gears: traps and long lines, cast nets and gill-nets with an average mesh size of 25 mm, but also smaller meshes are used. Unfortunately, one famous gear is the small Malinese trap. The trap has several inlets and a mesh size of 10-15 mm. Although, they are prohibited by law about 472 fishermen, each having between 10 and 20 traps, use them regularly, specially during drawdown, with an average catch of 17.7 kg per day (MORITZ *et al*. 2006). The mesh size is a good indicator of the state of the fishery even in regions where data on fish lengths are missing; since nets with small meshes are expensive and more labour-intensive farmers only adopt them out of necessity.

Personal observation on the local fish market of Malanville revealed that juveniles are sold regularly in huge quantities indicating the use of mesh sizes smaller than 10 mm (Fig. 5). Additionally, not only the mesh size used but also the quantity of nets stretched from one bank to another is alarming and especially during the dry season when fishing activities are restricted to the river channels nets are distributed over several kilometres of the rivers' reaches. An even more severe problem is the application of poisons to the rivers to kill the fish in order to reduce the work of catching them. This method has already been applied several times especially in the river Sota and experiences showed that even fatal casualties did not prevent people from continuing with this destructive activity.

Fig. 5: Juvenile fish sold on the local fish market (Malanville).

In summary, the fact that annual fish catches are declining whilst fishing effort is increasing highlights the scale of the threats to the natural fish stocks.

Therefore, the adoption of farming fish in fish holes ('Whedo'/'Tschifi dai') might represent an improvement of the management of the floodplain system by providing ways in which the needs of many users can be integrated harmoniously.

5. 'TSCHIFI DAI'/'WHEDO' OF THE NORTH OF BENIN

5.1 DEFINITION

'Tschifi dais' or 'Whedos' are small artificial depressions (median and mode 200 m^2) that are dug within the floodplain during the dry season. Fish migrating into the inundation zone during the rainy season are trapped when the water recedes. These fish holes are thence isolated from the river during the dry season and some farmers are stocking their holes additionally. High yields can be achieved by the "drain-in" principle that concentrates fish from the large floodplain area (WELCOMME 1975). Harvesting of the fish holes is conducted at the end of the dry season thus falling in the 'dead season' when farmers are usually not occupied with field work such as planting or harvesting.

However, the fishing season in the 'Tschifi dais' occurs shortly before the next season's agricultural activity, so it is not surprising that the revenue gained from the fish harvest has become an important element of support for purchasing agricultural equipment, seed and fertiliser.

5.2 HYDROLOGY

In general permanent pools cannot be summarized as one single or equal system, but have to be distinguished according to their location and consequently their hydrology.
In the commune of Malanville, 'Tschifi dais' differ significantly from each other and can be divided in three categories:

1. 'Whedos' flooded directly by the overspill of rivers and rain
2. 'Whedos' flooded indirectly through overflowing irrigation channels and rice fields
3. 'Whedos' only nourished through ground water and local rain.

Category 1: The majority of the 'Whedos' are dug directly in the fringing floodplain along the main rivers (Fig. 6). Therefore, these artificial pools first become connected with the river through heavy local rainfall flooding the plains adjoining the rivers. This inundation, Hari kouarè, has its peak in August/September. Subsequently, a second flood occurs in the dry season (November/December) due to the overspill of the Niger River. This flood, "Hari Bi", is a result of the heavy rainfalls in the highlands of Guinea draining into the headwaters of the Niger River. The flood crest takes about 100 days to move from Koulikoro (Mali) and therefore arrives in Malanville in the middle of the dry season. However, not all 'Whedos' become flooded twice, since it depends on along which river they are dug, their topography and position in the floodplain. Fish holes situated along the river Sota or in the borderland of the floodplain usually only experience a single inundation resulting from local precipitation and only become flooded a second time in years of unexpected intensity of the Hari Bi.

Fig. 6: 'Whedos' located in the floodplain of the River Niger

<u>Category 2:</u> In the vicinity of Malanville, 'Tschifi dais' are situated along the edge of the 'rice perimeter'. Since the perimeter is protected against uncontrolled inundation by a huge dam that has been constructed along the shore of the river Niger these 'Whedos' are not directly affected by its overspill. The 'Whedos' are flooded by heavy rainfall overflowing from the irrigation channels and rice fields and thus connecting the 'Whedos' indirectly with the river (Fig. 7).

Fig. 7: 'Whedos' located at the boundary of the 'rice perimeter' in Malanville

Category 3: These fish holes cannot be called 'Tschifi dais' in the narrow sense because they are not regularly connected with the rivers. These ponds are usually outside the floodplain area and are only connected with the rivers in years of unexpected heavy inundations as happened in 2007. Usually these fish holes are only replenished by local rain and particularly by high ground-water level. Consequently, in contrast to category 1 and 2, fish holes that are not situated within the floodplain have to be stocked artificially by their holders. Additionally, it should be mentioned that 'Whedos' of the category 3 are in the majority the result of bad planning of their owners and actually were thought to be of the category 1. A big part of them are drying up during the dry season as a result of low ground water table and lack of connectivity to the river. Therefore, one of the most important rules that should be followed is to dig the 'Whedo' at the end of the dry season, when ground water table is on its lowest level, to guarantee a permanent water supply.

6. MACROPHYTES OF THE HABITAT 'WHEDO'

The floodplain area is strongly influenced by the yearly flood regime and the depth, duration and amplitude of the flood have an impact on the floodplain vegetation. Seasonality leads to a succession of the plant communities as well as their distribution pattern found in and around the 'Whedos'. Consequently, floodplain vegetation can be classified in two distinct plant communities, one in the dry and one in the wet season. In the following chapter, we try to describe those vegetation patterns and also their alteration in the course of the year as well as their influence on the local ecosystems, particularly the water quality of the 'Tschifi dais'. Furthermore, we will present the typical dry season-zonation of plant species established around the permanent 'Whedos' in the floodplain of the study area (Chapter 6.3).

6.1 SEASONALITY OF THE FLOODPLAIN VEGETATION

During inundation, which is initially provoked by local rains as well as land drainage in July to September and later on maintained by the overspill of the river Niger, large areas are flooded leading to the submergence and subsequent death of the terrestrial plants. The decay of organic material (vegetation, manure from livestock etc.) and the resulting nutrient enrichment of the standing or still water promote a rapid growth of free-floating macrophytes (WELCOMME 1985) like *Eichhornia crassipes* (water hyacinth) and *Pistia stratiotes* (water lettuce) as well as the bottom-rooted hydatophyte *Nymphea spp.* which later on dominate the floodplain area. But also flood-tolerant grasses and sedges (*e.g. Typha domingensis, Cyperus* sp*., Paspalum scrobiculatum* and *Echinochloa colona*), were common on shallow banks.

With the onset of the dry season, the water level of the 'Whedos' declines significantly and aquatic plants become exposed and subsequently die. However, part of this plant community becomes restricted to permanent pools ('Whedos'), whilst the greater part of the dried-up floodplain area is invaded rapidly by plant species that are essentially terrestrial.

6.2 ZONAL CLASSIFICATION OF THE VEGETATION

As a result of the high evaporation rates during the dry season, the water level declines and a marginal flood zone is found around permanent pools. The vegetation around the 'Whedos' is arranged in belts according to the depth of the water and water saturation of the soil. Since pools are shrinking in the course of the dry season these vegetation belts are not fixed and thus the marginal vegetation represent a permanent succession. Only the deepest core-areas of the pools remain with a stable cover of *Nymphaea*-species (Fig. 8).

Fig. 8: *Nymphea* spp. at the deepest spot of the 'Whedo'

We classify the vegetation around the 'Whedos' into three main categories by slightly modifying the categories according to HEJNY (1960) and allocate them to specific zones, that is, to different vegetation belts (Fig. 9):

1. Hydatophytes: Plants whose vegetative parts must be completely submerged or supported by water for the generative cycle to be completed.

Zone A: Deep water zone (deeper than 0.6 m) *e.g.* bottom-rooted *Nymphaea* spp. and *Marsilea* sp.

Zone B: Medium flooded zone (0.2 – 0.6 m) *e.g.* free-floating *Lemna aequinoctialis* and *Pistia stratiotes*.

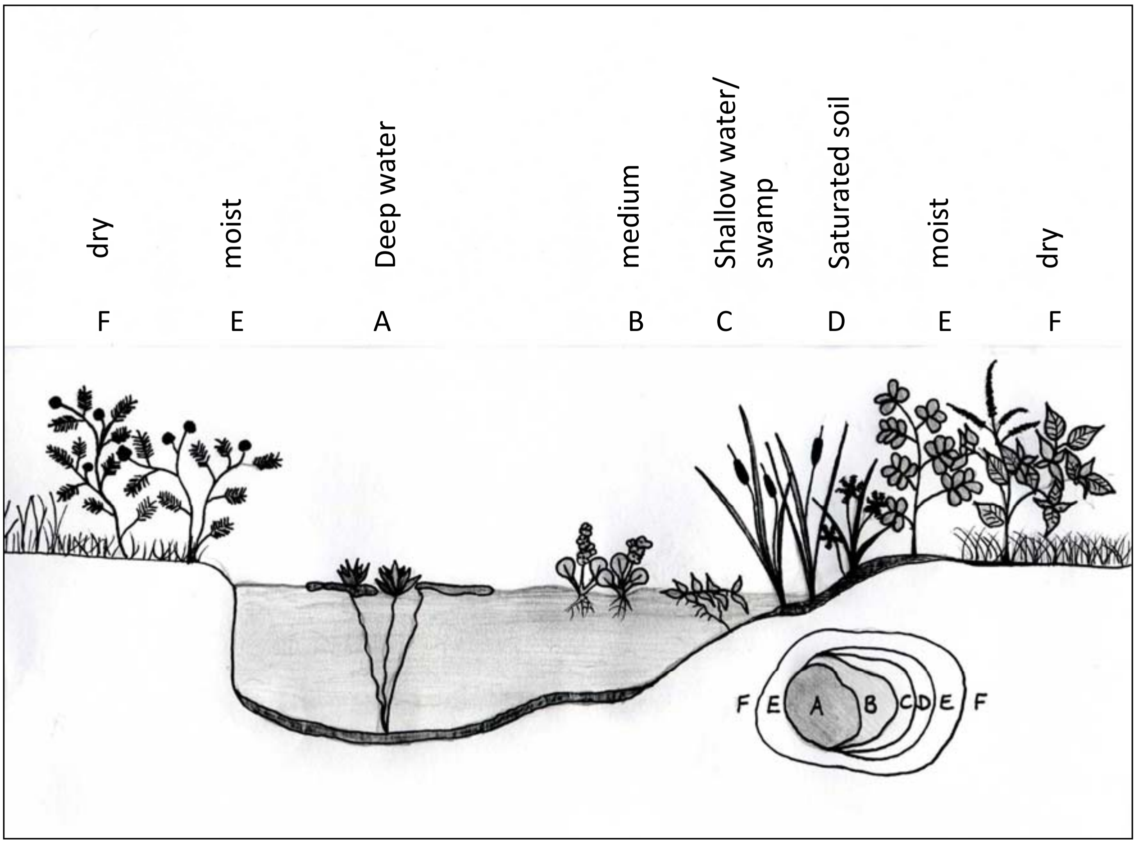


Fig. 9: Different vegetation belts around the 'Whedos'. Explanations of the respective zone are given in the text.

2. Tenagophytes: Plants that may or may not have a submerged phase, but must have at least some vegetative parts emerging from the water and standing free in the air for sexual reproduction to occur.

Zone C: Shallow flooded/swamp area (to 0.2 m) *e.g. T. domingensis, E. colona, Commelina benghalensis, Neptunia oleracea, Mimosa pigra, Sesbania rostrata, Ipomoea aquatica* and *Ludwigia* spp.

Zone D: Saturated soil *e.g. Chrysopogon nigritanus*, *Cyperus submicrolepis, Aeschynomene afraspera, Cynodon dactylon.*

3. Trichophytes: Plants that are essentially terrestrial but can tolerate short periods of flooding.

Zone E: Moist soil *e.g. Cassia mimosoides, Cleome viscosa, Coldenia procumbens* and *Heliotropium indicum.*

Zone F: Dry soil e.g. *Amaranthus viridis, A. spinosus* and *Setaria pumila.*

However, the plant species recorded are not restricted to an exclusive zone. Table 2 reports 65 species from 30 families identified around the fish holes with their accompanying zonal categorisation. Moreover, not all species were recorded around each pool and vegetation differed according to the slope of the bank as well as the soil type. Fish holes with a steep-edged bank mostly due to erosion do not possess the zones C and D, while other pools with a broad flat slope of the bank are almost entirely covered by zone C and D helophytes, such as *T. domingensis* and *Cyperus* sp., leading to an increased siltation of these fish holes.

6.3 Influence of water quality on the vegetation and vice versa

In the 'Whedos' that were investigated, no submerged plants were found. This is a consequence of high turbidity as well as abundant floating aquatics, reducing light penetration into the water column. Denny (1985) defines the lack of submerged vegetation as a consequence of turbidity and the competition for light and space with surface-floating and emergent plant species. In additional, also the marginal intraday fluctuations of dissolved oxygen and pH in the 'Whedos' indicate a low photosynthetic activity. This suggestion is also supported by Welcomme (1979), who reported that primary production in the floodplain is mostly concentrated in the higher vegetation. Apart from direct shading, excessive growth of macrophytes (both floating and sessile, Fig. 10) also reduces light penetration due to associated organic material suspended in the water. In several ponds, the water contained high amounts of floating small blackish particles and an accumulation of fine organic material could be observed at the pond bottom. When churned up and exposed to the water surface, this thick layer releases displeasing smell of hydrogen sulphide, thus representing a risk of causing fish mortalities.

In 'Whedos' intensely covered with free-floating macrophytes measurements of dissolved oxygen (DO) in different depths (10 cm steps from the surface to the bottom) showed that concentration was, in general, very low in all layers and did not fluctuate in the course of the day and also not between the different depths. In comparison, 'Whedos' without plant cover, or less than 50 percent, showed a significantly higher level of DO and additionally also a slight increase in concentration from the morning to midday. Apart from shading the water column and the decomposition of organic matter, free-floating vegetation possibly reduces oxygen concentrations due to decreased wind-exposed surface area and wave action of the pool.

Fig. 10: Extensive growth of macrophytes covering the water surface of the 'Whedo'.

6.4 FREE-FLOATING VEGETATION

However, the presence and density of free-floating vegetation, especially *P. stratiotes* and *E. crassipes*, depends on nutrient level of the water (HENRY-SILVA *et al.* 2008). The majority of nutrient-rich 'Whedos' were completely covered with either *E. crassipes* or *P. stratiotes,* while nutrient poor pools were invaded to a lesser extent. Moreover, in our investigations, highly covered pools were dominated by a single free-floating species, mostly *Eichhornia crassipes,* and thus are in accordance with PETR (2000) who showed that two similar species scarcely ever occupy similar niches.

Also the formation of 'Sudd' (*Arabic* 'blockage') or floating meadows forming a so called aquatic prairie (JOHN 1986) could be observed consisting mainly of *Poacea*-species such as *Echinochloa colona* and *Paspalum scrobiculatum* and bound together by other species normally found in zone C, *e.g. N. oleracea, Ludwigia* spp*., I. aquatica*, *Cyperus* sp., *Echinochloa* sp*.* and *Ludwigia* sp.

Tab. 2: Plant species recorded in and around the 'Whedos' allocated to different zonation: A – deep water; B – medium flooded; C – shallow flooded/swamp; D – saturated soil; E – moist soil; D – dry soil.

Plant family/species	**Vegetation zones**					
	A	**B**	**C**	**D**	**E**	**F**
Acanthaceae						
Monechma ciliatum (Jacq.) Milne-Redh.					●	●
Nelsonia canescens (Lam.) Spreng.				●	●	
Aizoaceae						
Mollugo nudicaulis Lam.			●	●	●	
Trianthema portulacastrum L.					●	●
Amaranthaceae						
Alternanthera nodiflora R.Br.			●	●	●	
Amaranthus viridis L.					●	●
Amaranthus spinosus L.					●	●
Pupalia lappacea (L.) A.Juss.					●	●
Araceae						
Pistia stratiotes L.	●	●				
Asteraceae						
Acanthospermum hispidum DC.					●	
Eclipta prostrate L.			●	●	●	
Azollaceae						
Azolla africana Desv.		●	●			
Boraginaceae						
Coldenia procumbens L.				●	●	●
Heliotropium indicum L.					●	●
Capparaceae						
Cleome viscosa L.					●	●
Commelinaceae						
Commelina benghalensis L.			●	●		
Convolvulaceae						
Ipomoea aquatica Forssk.			●	●		
Merremia hederacea (Burm.f.) Hallier f.					●	
Cucurbitaceae						
Cucumis melo L.					●	
Cyperaceae						
Cyperus alopecuroides Rottb.			●	●		
Cyperus imbricatus Retz.			●	●	●	
Cyperus esculentus L.			●	●		
Cyperus pustulatus Vahl			●	●		
Cyperus submicrolepis Kük.			●	●		
Fabaceae						
Aeschynomene afraspera J.Léonard			●	●	●	
Alysicarpus ovalifolius (Schumach.) J.Léonard				●	●	●
Chamaecrista pratensis (R.Vig.) Du Puy			●	●	●	●
Cassia obtusifolia L.			●	●		
Crotalaria retusa L.					●	●
Mimosa pigra L.			●	●	●	
Neptunia oleracea Lour			●	●		
Sesbania rostrata Bremek. & Oberm.			●	●		
Tephrosia bracteolata Guill. & Perr.				●	●	
Tephrosia nana Schweinf.				●	●	
Lemnaceae						
Lemna aequinoctialis Welw.	●	●				
Malvaceae						
Hibiscus mechowii Garcke					●	●
Hibiscus asper Hook.f.					●	●
Urena lobata L.					●	●
Marsileaceae						
Marsilea sp.			●			
Nyctaginaceae						
Boerhavia erecta L.				●	●	●
Nymphaeaceae						
Nymphaea lotus L.	●					
Nymphaea micrantha Guill. & Perr.	●					
Onagraceae						
Ludwigia abyssinica A. Rich.		●	●	●		
Ludwigia adscendens (L.) Hara		●	●	●		
Ludwigia erecta (L.) Hara		●	●			
Parkeriaceae						
Ceratopteris cornuta (Beauv.) Le Prieur		●	●			

Tab. 2: continued

Plant family/species	**Vegetation zones**					
	A	**B**	**C**	**D**	**E**	**F**
Poaceae						
Brachiaria sp.			●	●	●	●
Chrysopogon nigritanus (Benth.) Veldkamp			●	●	●	
Cynodon dactylon (L.) Pers.		●	●	●	●	
Dactyloctenium aegyptium (L.) Willd.					●	●
Echinochloa colona (L.) Link		●	●	●		
Oryza sativa L.			●	●	●	
Paspalum scrobiculatum L.			●	●	●	
Setaria pumila (Poir.) Roem. & Schult.					●	●
Polygonaceae						
Persicaria lanigera (R.Br.) Soják			●	●	●	
Persicaria senegalensis (Meisn.)			●	●	●	
Pontederiaceae						
Eichhornia crassipes (Mart.) Solms	●	●				
Portulacaceae						
Portulaca oleracea L.				●	●	●
Scrophulariaceae						
Bacopa crenata (P.Beauv.) Hepper			●	●		
Solanaceae						
Physalis angulata L.					●	●
Sterculiaceae						
Melochia corchorifolia L.					●	●
Melochia melissifolia Benth.				●	●	●
Tiliaceae						
Corchorus olitorius L.					●	●
Typhaceae						
Typha domingensis Pers.			●	●		
Verbenacea						
Stachytarpheta indica (L.) Vahl					●	●

6.5 Impact on human activities

In general, aquatic plants grow rapidly occupying the increasing wetland area. In the commune of Malanville, the pan-tropical water hyacinth, considered as among 100 of the world's worst invaders (IUCN/SSC 2010; Henry-Silva *et al.* 2008) is already widespread and its more recent explosive growth has interfered with fishing on the floodplains (including the 'Whedos') and rivers as well as choking landing places such as the river mouth of the Sota (Fig. 11) and still branches of the Niger at the city Malanville. Fishermen are permanently occupied in keeping the navigation lane free of the fast developing vegetation mat.

Recently a governmental project is teaching farmers how to compost water hyacinth and to use the compost as organic fertilizer especially for the increasing rice cultivation. For this purpose several depressions were constructed along the agricultural fields that should serve as composting places. Along the 'Whedos' we could also observe that some farmers burn the stranded aquatic vegetation after the desiccation of the floodplain leaving the ash on the field to enrich the soil for further cultivation.

Earlier projects tried to use water hyacinth as livestock feed, but especially the cows refused to feed on them. But nevertheless, it is a common practice during the rainy season when the floodplain are not accessible to the animal herds that livestock breeders meaning primarily their children are cutting fodder grasses that are bound together to big bags and transported to the animals to provide them fodder. Furthermore, for the rural population macrophytes such as *Typha* sp. and *Cyperus* spp. are important for the construction of their roof and other basic commodities.

Fig. 11: Massive mats of water hyacinth in the river Sota clocking the landing place at Malanville.

7. WATER PARAMETERS OF THE 'TSCHIFI DAIS'

Knowledge of water quality is essential to assess the suitability of 'Whedos' for fish production and the choice of species appropriate for successful stocking. However, the data available for the 'Whedos' in the Ouémé Delta (see LALÈYÈ *et al.* 2007; TOKO 2007) differ significantly from those in the North in response to the different climatic conditions. Differences are especially pronounced in the relatively low conductivity, the more acid pH and the low nitrate concentrations of the 'Whedos' in the Ouémé delta which is probably the result of their direct connectivity to the river.

This chapter will give a general overview on the water properties of the 'Whedos' investigated (7.1) as well as a closer look on the parameters most important for the successful farming of fish in these permanent pools (7.2).

7.1 WATER QUALITY ACCORDING TO HYDROLOGY AND SEASONALITY

A first overview of the water chemistry of the 'Whedos' and the river channels is given in Table 3. Data are presented as minimum and maximum values since they summarize all measurements during the dry season (March to June) as well as the rainy season (July to September). Moreover, 'Whedos' are distinguished in river-flooded and channel-flooded according to the categories already presented in chapter 5.

In the majority, water quality differs significantly between the two types of 'Whedos' and the river channels. These discrepancies are especially pronounced during the dry season and significant differences in dissolved oxygen concentration (DO) and conductivity could be recorded between the channel-flooded 'Whedos' and the rivers.

Although, also the river-flooded 'Whedos' show higher conductivity and lower DO levels in comparison to the rivers these differences are not significant. Channel-flooded 'Tschifi dais' and river sites still differ significantly in their hardness, alkalinity, phosphorous (P) concentration and Secchi Disk Depth (SDD), but no significant differences could be recorded between the river-flooded 'Whedos' and the river channels.

This relative similarity between the river and the river-flooded 'Whedos' might explain their relatively similar fish species composition, whereas channel-flooded 'Whedos' have comparatively a significant reduced species composition (more in chapter 9). SDD in the River Niger showed a reduced level in the wet season when the river carries a high sediment load resulting from strong local rain and the consequent run-off and erosion.

With regard to the 'Whedos', SDD was generally negative correlated to the iron concentration ($r = -0.59$, $t = -3.32$, $P = 0{,}003$, $n = 23$) indicating an increased amount of soil suspended in the water leading to reduced transparency.

Monthly mean values of the different water parameters of the 'Tschifi dais' mostly undergo strong variations, whereas water quality of the rivers remains relatively constant (Fig. 12). With regard to the channel-flooded 'Whedos', nitrogen (ammonium, nitrate and nitrite) as well as phosphorus concentrations increased strongly in August reflecting the inflow of nutrient-enriched water from the previously fertilized rice fields.

In the case of the river-flooded 'Whedos' the concentration of ammonium, nitrite, as well as DO decreased while the concentration of nitrate increased. This might be evidence of the enhanced nitrification under the use of free oxygen.

Tab. 3: Water chemistry of channel-flooded, river-flooded 'Whedos' and the rivers in the rainy as well as dry season.

		Rainy season			**Dry season**		
		RF	**CF**	**River**	**RF**	**CF**	**River**
Temp. (°C)	**Mean**	27,1	26,9	28,1	27,4	27,3	28,9
	Min	26,3	26,3	27,2	23	26,5	28,2
	Max	28,1	27,8	29,3	30,3	28	29,7
DO (mg/L)	**Mean**	2,5	2,3	5,6	2,6^{ab}	2,2^{a}	7,3^{b}
	Min	1,0	1,8	3,1	1,2	1,3	6,9
	Max	3,5	3,0	6,8	5,6	4,7	7,8
pH	**Mean**	6,57	7,15	6,70	7,0^{a}	7,33^{b}	7,06^{ab}
	Min	5,81	6,74	6,67	6,45	6,83	6,85
	Max	7,59	7,52	6,74	7,62	7,52	7,27
EC (µS/cm)	**Mean**	570^{ab}	1418^{a}	57^{b}	966^{ab}	1739^{a}	54^{b}
	Min	81	412	49	133	847	39
	Max	2129	3092	70	2896	2659	69
TH (°dH)	**Mean**	6^{ab}	17^{a}	2^{b}	12^{a}	22^{b}	4^{c}
	Min	2	10	2	4	13	2
	Max	18	29	3	30	32	6
CH (°dH)	**Mean**	5^{ab}	15^{a}	2^{b}	7^{a}	16^{b}	0^{c}
	Min	2	10	1	0	9	0
	Max	17	20	3	13	25	1
NH_4 (mg/L)	**Mean**	0,12	0,11	0	0,96	0,37	0,21
	Min	0	0	0	0	0,13	0,18
	Max	0,30	0,33	0	3,11	1,30	0,24
NO_3 (mg/L)	**Mean**	5,66	14,50	7,22	2,82^{a}	7,23^{b}	3,08^{ab}
	Min	3,33	4,67	5	1	3	2,67
	Max	10	44,33	11,67	7,5	28,83	3,5
NO_2 (mg/L)	**Mean**	0,05	0,12	0,2	0,15^{ab}	0,16^{a}	0,01^{b}
	Min	0,00	0,02	0,2	0,02	0,03	0,01
	Max	0,28	0,34	0,2	1,68	0,36	0,02
P (mg/L)	**Mean**	0,14^{ab}	0,55^{a}	0^{b}	0,38^{a}	0,59^{b}	0,26^{c}
	Min	0,02	0,28	0	0,15	0,45	0,19
	Max	0,27	0,95	0	0,94	0,93	0,33
Fe (mg/L)	**Mean**	n.r.	n.r.	n.r.	0,47	0,26	0,08
	Min	n.r.	n.r.	n.r.	0,05	0,08	0,06
	Max	n.r.	n.r.	n.r.	1	0,54	0,10
SDD (cm)	**Mean**	21,1^{ab}	31,4^{a}	11,4^{b}	12,2^{a}	17,3^{ab}	32^{b}
	Min	9	24,5	6,3	1,3	8,3	23,8
	Max	32,2	43	15,7	23,4	25,4	40,2

Temp. = Water temperature; DO = Dissolved Oxygen; EC = Electric Conductivity; TH = Total Hardness in 'deutscher Härte'; CH = Alkalinity/Carbonate Hardness in 'deutscher Härte'; Fe = Iron; SDD = Secchi Disk Depth; n.r. = not recorded. Values with different superscripts accentuate significant differences ($P < 0.05$).

Additionally, the decrease in oxygen concentration is probably also the consequence of the mixture of the anaerobic pond bottom layer with the more oxygen rich surface induced by the strong rainfalls and wind action. Anaerobic conditions at the pond bottom are also confirmed by the smell of rotten eggs indicating the presence of hydrogen sulphide.

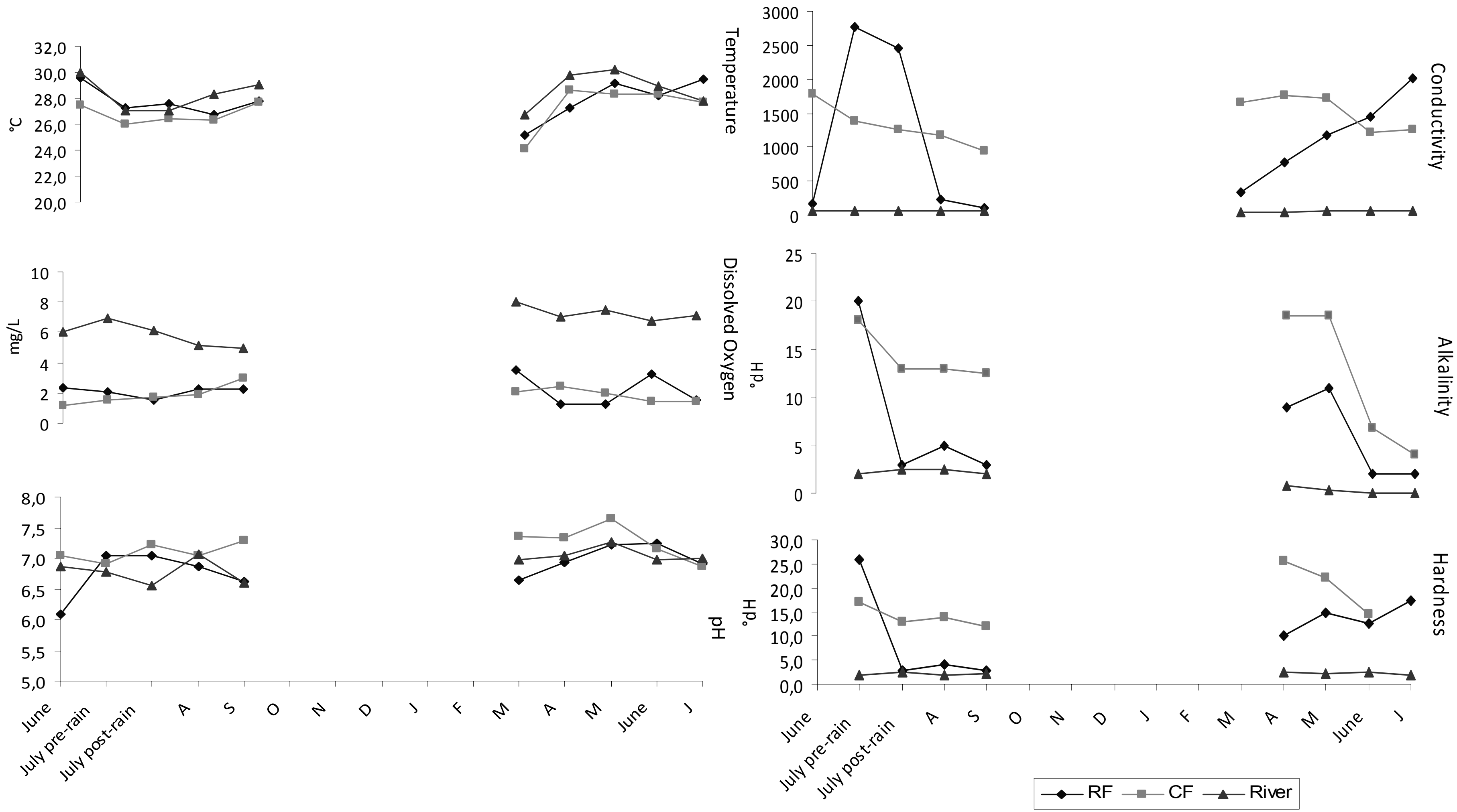


Figure 12: Monthly variation of different water parameters for RF (river-flooded 'Whedos'), CF (channel-flooded 'Whedos') and the Rivers

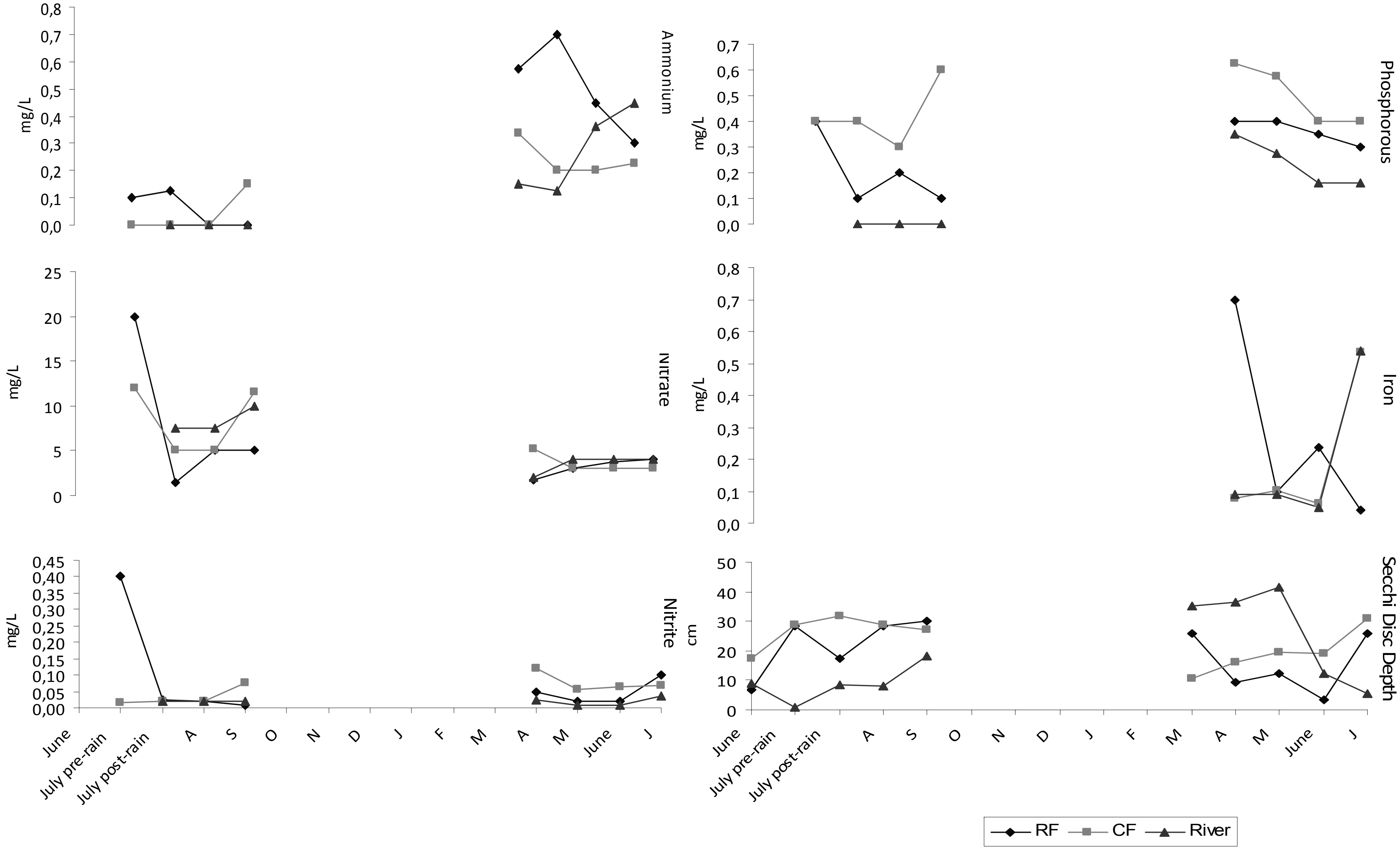


Figure 12: Continued

With the onset of the rainy season total hardness as well as carbonate hardness decreased in all 'Whedos' because of the dilution of the pond water by the very soft rain water (°dH = 2 or ~36mg/L $CaCO_3$).

Additionally, with the onset of the rainy season, pH as well as conductivity might temporary increase because nutrients from terrestrial resources are flushed into the floodplain pools (GTZ 2002; WELCOMME 1979). Especially 'Whedos' situated near public places showed a strong increase of conductivity and pH with the onset of the first heavy rainfall caused by the high input of organic substances (manure, faeces and human wastes) and waste that accumulated round the 'Whedos' (Fig. 13).

Fig. 13: Strongly polluted 'Tschifi dai'.

This phenomenon can be illustrated by regarding the changes observed in one selected 'Whedo' located at the edge of the 'rice perimeter' and close to a primary school that usually have high amounts of organic load in their closer environment as a result of a lack of sanitary facilities (Fig. 14). But this solution effect is just short-term and by comparing the overall water characteristics of the dry season with those of the rainy season pH, conductivity, nitrite and ammonium decreased in the course of the rainy season as a consequence of dilution effects

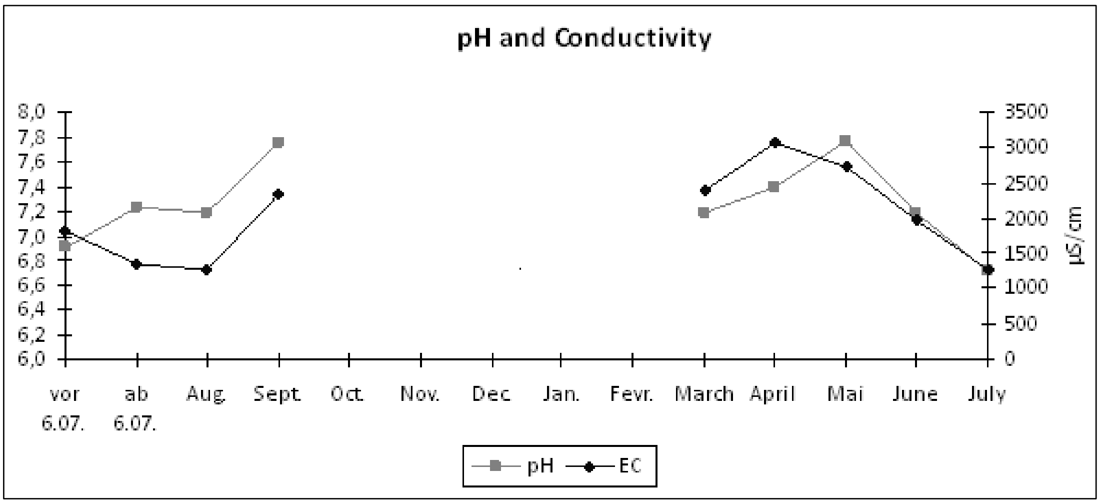


Fig. 14: Monthly variations in pH and conductivity (EC) for one selected channel-flooded 'Whedo' located nearby public places.

Another important factor affecting the water quality of the 'Whedos' is the abundance or the degree of free floating vegetation mats. By comparing water parameters of 'Whedos' covered (> 50 %) with those not or less covered (< 50 %) we noticed significant differences with covered 'Whedos' showing higher concentration of nitrite and phosphorous (Hauber *et al.*, in prep.). However, 'Whedos' covered by macrophytes showed significantly higher SDD probably as a result of reduced wave and wind activity allowing the settlement of suspended particles and sediments. Moreover, circadian measurements in one of the covered 'Whedos' showed clearly that DO concentration did not change significantly with the course of the day but remained relatively constant (Fig. 15) and thus led to the assumption that the shading of the water column inhibits photosynthetic activity by phytoplankton.

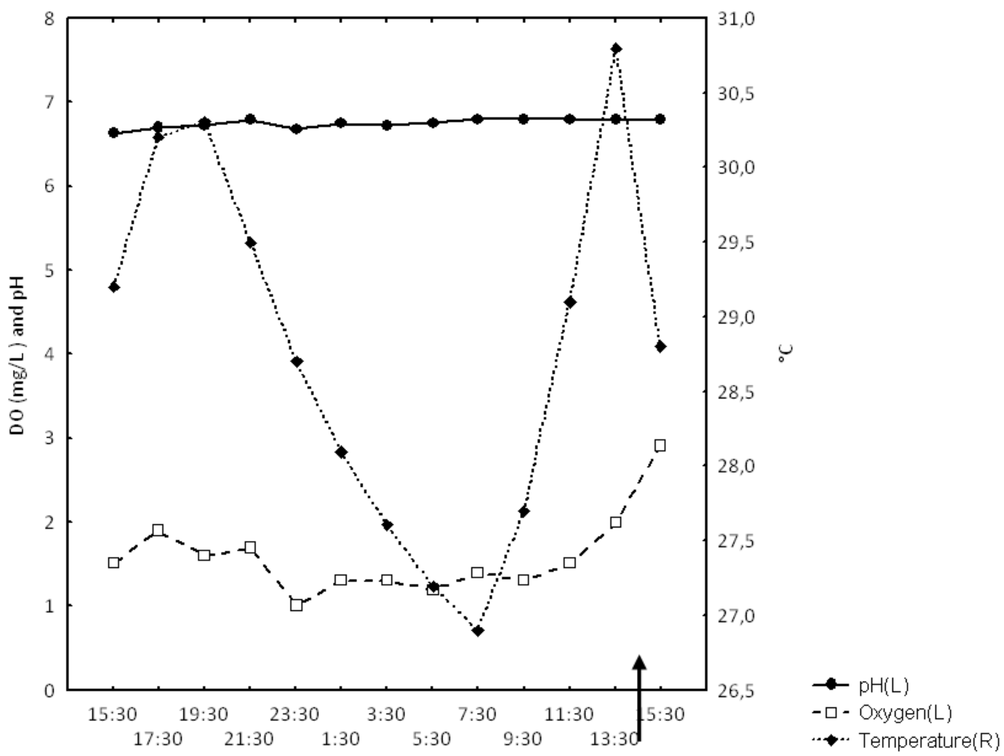


Fig. 15: Diurnal variation of dissolved oxygen, water temperature, conductivity as well as pH for one of the channel- flooded 'Whedos' at the beginning of the rainy season in July. The arrow indicates the onset of an intense rainfall.

The increase of DO and the temperature drop recorded at 3.30 p.m. was the result of a very strong rain.

Further analysis were done in different depth (from the surface to the bottom) to determine DO and temperature changes in covered and uncovered 'Whedos'. Results showed again that in covered 'Whedos' DO concentrations are generally quite low and remained relatively constant whereas uncovered 'Whedos' combined with high transparency showed an important increase of DO in all depths in the course of the day.

7.2 Suitability of the water quality for fish production

To conclude this chapter we will have a closer look at some of the previously described parameters relating to the suitability of the water quality for fish production.

Dissolved oxygen is the most important parameter in aquaculture and consumption by fish is directly linked to size and feeding rate. To obtain good growth DO levels of about 5 mg/L should be maintained according to Swann (2007). However, maximum oxygen levels of the different kind of 'Whedos' rarely exceed 5 mg/L and in several 'Whedos' diurnal values are even low as 0 mg/L.

Although, the majority of adult fish are tolerant to salinity levels of 14,705 µS/cm, juvenile fish require concentration between 6,600 and 7,300 µS/cm (Hart *et al.* 1991; Dunlop *et al.* 2005). However, in the early life stages of development, juvenile, especially pre-hardened eggs are more vulnerable to increased salinity and concentration should be in the range of 3,000 to 6,600 µS/cm, whereas for some species the threshold is already reached at a lower level (Dunlop *et al.* 2005). Thus, considering the salinity prevailing in the observed 'Whedos', especially during the dry season, concentrations find themselves in the range of brackish water (GEC, 2008) and might not be suitable for sensitive juvenile fish species. But apart from vertebrates, invertebrates, *e.g.* certain water-bugs, seem to be more sensitive to salinity levels with adverse affects apparent for some species at salinities low as 1,470µS/cm (Hart *et al.* 1991). Therefore, the concentration of 4,999 µS/cm prevailing in some 'Whedos' might indirectly affect growth and survival of *e.g.* benthos feeding fish since natural food supply that consists to a big portion of vertebrates might be insufficient.

Considering the median pH values of the different types of 'Whedos' they are always in the acceptable range of 6.5 to 9 recommended for fish culture (Swann 2007).

Although there are no direct effects of alkalinity and hardness on fish they are important parameters for the stability of the water quality and as carbon dioxid storage. According to Buttner *et al.* (1993) hardness should be above 50 ppm calcium carbonate, corresponding to about 2.8°dH, whereas the suitable range of alkalinity is between 20 to

300 ppm CaCO3 or 1.1 to 16.7°dH, respectively. The values of the 'Whedos' are lying within these ranges and thus should not create any obstacles.

Considering the nitrite load SWANN (2007) gives concentrations of 0.1 mg/L in soft water and 0.2 mg/L in hard water as limit for continuous exposure of fish, whereas BUTTNER *et al.* (1993) gives values of < 1 mg/L as preferred level for fish culture. In general, tolerance levels depend highly on the respective species but nitrite concentration of some 'Whedos' exceeds the tolerance ranges of many fish species. Although, nitrate values are also lifted, especially in the channel-flooded ones, it should not represent a problem since aquatic species can tolerate extremely high concentrations of more than 100 mg/L NO_3-N (ALAM & AL-HAFEDH 2006) or several hundred mg/L of nitrate (BUTTNER *et al.* 1993).

Total phosphorous varied between 0.08 and 0.56 mg/L and thus is well in the recommended range of 0.01 to 3 mg/L (SWANN 2007). Iron originating from the groundwater and sediments can settle on fish gills causing irritation and stress and therefore should be kept in the range of 0.0-0.5 mg/L in warm water (BUTTNER *et al*. 1993). Although, there are some 'Whedos' with higher iron concentrations, the majority is within the acceptable range.

The high turbidity represents one of the major constraints in regard to the water quality. Apart from reducing light penetration and thus photosynthetic activity turbidity may also destroy beneficial communities of bottom organisms, irritate fish gills and affect sight feeding fish in finding and capturing their food (SWANN 2007) and thus should be kept as low as possible.

Summarized, water parameters of the 'Tschifi dais' undergo significant changes in the course of the year resulting in very adverse conditions during the dry season. Comparisons between the two types of '·Whedos' showed that channel-flooded 'Whedos' suffer from high inputs of nutrients, especially in view to nitrite. Additionally, also conductivity is quite high in some 'Whedos' which is also reflected in the relatively low species composition (HAUBER *et al.* 2011a). Thus, sites for 'Whedo' construction should be selected carefully and water that passes rice fields or polluted areas (public places) before entering the 'Whedos' should be avoided. However, the very low dissolved oxygen concentrations, high conductivity as well as elevated nitrite concentrations in the observed 'Tschifi dais', especially during the dry season, restrict the choice of species for aquaculture to air breathing or adapted fish species such as *Clarias gariepinus*, *Heterobranchus longifilis* or *Protopterus annectens*.

8. GEOLOGY AND MAJOR SOIL CHARACTERISTICS

8.1 GEOLOGY OF THE COMMUNE MALANVILLE

In general, the topography of Malanville is composed of plains and valleys impeded between the River Niger and some ferruginous hilly plateaus. The hills, with an altitude of about 80 m, converge in the district of Madécali, Malanville as well as Guéné (PRODECOM 2006). According to AREGHEORE (2009) the major soil types in the North of Benin are tropical ferruginous soils developed on granito-gneissic formations. The commune of Malanville is located on sandy argilliferous soils (PRODECOM 2006; WILLAIME & VOLKOFF 1963).

The environment of Malanville possesses a varying ground water table that is generally more elevated in the Western than in the Eastern part of the commune, where it is drained by a huge marsh land extending to the neighbouring country Nigeria. The average level of the ground water table is about 5 meters (PRODECOM 2006).

8.2 MAJOR SOIL CHARACTERISTICS OF THE 'WHEDOS'

Soil characteristics, particularly soil texture, organic matter composition and element composition have critical implications for the performance of any kind of farming systems. Generally, pond soils play an important role in influencing the concentration of nutrients in the water. This in turn regulates the abundance of phytoplankton, being the first step in the food chain for the fish stocked in the 'Whedo'. Therefore, this section describes the most important soil parameters of the 'Whedos'. Soil samples were taken to a depth of approximately 15 cm at three sites of the respective 'Whedo' and thoroughly mixed to provide one composite sample for analysis. Results of the analysis of their physical and chemical properties are listed in Table 4.

The sediment thickness varies significantly from one 'Whedo' to the other. Whereas there are 'Whedos' with thin (< 5 cm) sediment layers, mostly newly constructed on sandy sites, there are also several 'Whedos' possessing sediments layers thicker than 25 cm sometimes even reaching to the knees (Fig. 16). These sediments are soft and originate mainly from decomposed plant materials, fish faeces as well as from eroded embankments and alluvial soil arriving with the annual flood.

Tab. 4: Physical and chemical properties of soil samples collected in 'Whedos' in the environment of Malanville (Benin).

Parameters	Mean	Min.	Max.
pH	6.3	4.7	7.9
Organic Carbon (%)	1.7	0.1	4.1
P (ppm)	19.8	1.1	92.6
Total N (%)	0.30	0.08	0.55
C:N ratio	5.7	1.2	15.6
Na (cmol+/kg)	2.6	1.1	17.0
K (cmol+/kg)	1.2	0.1	9.6
Mg (cmol+/kg)	2.2	0.2	12.3
Ca (cmol+/kg)	1.7	0.0	6.5
Fe (ppm)	530.3	288.8	863.1
Clay (%)	11.2	1	35
Silt (%)	8	0	34
Sand (%)	79	31	98

Considering the 'Whedos', their soil organic carbon (OC) content ranges between 0.15 - 4.12 percent, thus according to BOYD *et al.* (2002b), are categorised as mineral soil with high OC content (3.1 to 15 percent) or mineral soil with moderate OC content (1 to 3 percent) representing the best range for aquaculture. Soil analyses of the different 'Whedos' showed clearly that OC concentration increased with the age of the pond and new ponds and/or ponds with sandy bottoms showed the lowest concentrations of OC.

Fig. 16: Knee-high mud exposed after final harvest of the 'Whedo'

Nevertheless, because of the abundance of decaying organic matter, particularly from floating macrophytes, the demand for DO by decomposers exceeds the rate that DO can diffuse to the bottom. Besides the analyses of the pond bottom water, also the malodour and the black colour of the very fine particles stirred up from the pond bottom indicate the presence of hydrogen sulphide developing under anaerobic conditions.

Considering primary production, phosphorous (P) and nitrogen (N) are the most important nutrients in aquaculture because they are often in short supply and are responsible for depressed phytoplankton growth. With regard to the 'Tschifi dais' total N of the pond soil is in the range of 0.08 to 0.55 percent with an average of 0.30 percent, whereas the C:N-ratio has a mean of 5.7. This ratio stands for the activity of soil microbes. The optimum for fish production ranges between 10 and 15 (ADHIKARI 2003) meaning the values measured for the 'Tschifi dais' indicates a very fast mineralization rate and thus an increased risk of anaerobic conditions at the sediment-water interface.

Phosphorous content (Mehlich P) of the 'Whedo' bottom soils ranged between 1.4 and 92.6 ppm. Generally, pond bottoms absorb phosphorous at a high rate and with regard to our samples, available P was decreasing with increasing clay content ($r = -0.60$; $t = -2.9$; $P = 0.01$; $n = 17$), whereas available P was positive related to the percentage of sand in the pond soil ($r = 0.64$; $t = 3.2$; $P = 0.006$; $n = 17$). Because P is usually rapidly absorbed by the soil only a small amount will enter the water and thus be available to aquatic life. Maximal availability of absorbed soil P occurs at a pH of about 7.

The pH of the 'Whedo' bottom soils vary from 4.7 to 7.9 (Fig. 17), whereas the mean value was 6.3 (median = 6.8; standard deviation = 1.1; n =20) showing that bottom soils in the study area are rather acid. Expectedly, our analysis are in agreement with the investigations of BOYD & MUNSIRI (1996) who recorded that acidic soils usually have low alkalinity as well as total hardness concentration.

Together with nitrogen and phosphorus, potassium (K) belongs to the group of major nutrients required for phytoplankton growth. In general, relatively small potassium concentration are needed in fish ponds and in view to the 'Whedo'-soils exchangeable K ranged between 0.1 to 9.6 $cmol^+/kg$ with an average of 1.2 $cmol^+/kg$ referring to 39.1 to 3 754 mg/kg and an average of 469.2 mg/kg, respectively.

Apart from chemical properties, physical characteristics of the soil, for example soil texture, are of high importance for aquaculture practices. Most commonly applied classifications of soils are the textural classification systems for mineral soils (SOIL SURVEY STAFF 1975, 1990) used by the U.S. but since for aquaculture the physical nature of one single soil layer is more important, BOWMAN & LANNAN (1995) introduced a new classification system that categorises the pond bottom layer in clayey, fine-loamy, coarse-loamy or sandy particle-size classes.

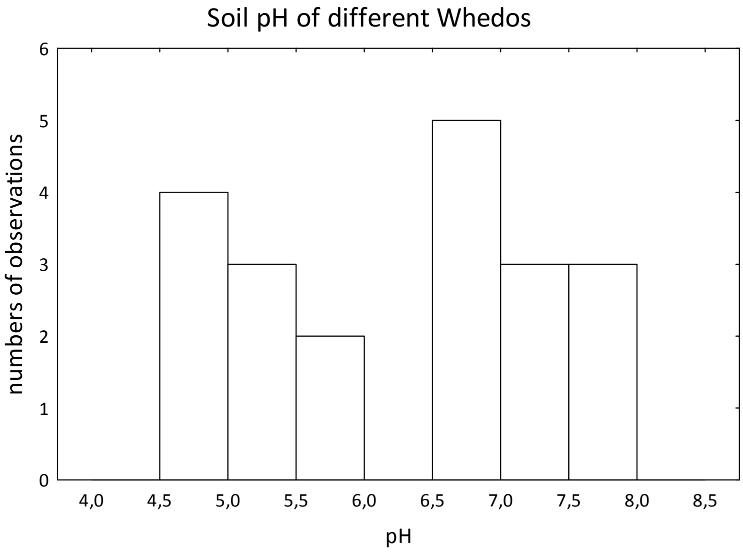


Fig. 17: Soil pH of different 'Whedos'

By applying this classification system 66.7 percent of the pond soils of the investigated 'Whedos' are sandy, 11 percent coarse loamy, 16.7 percent fine loamy and 5.6 percent clayey. In the past it was recommended by many authors (*e.g.* BOYD & BOWMAN 1997) that soils for pond construction should contain 20 – 30 percent of clay to prevent seepage. But because of the instability of embankments with such high clay content and also because of the difficulties in handling these heavy soils, 5 – 10 percent of clay is preferable for pond construction (BOYD *et al.* 2002). Although the sand fraction is quite high in the majority of the 'Whedos' and might indicate low water holding capacity, seepage does not represent a problem meaning 'Whedos' usually hold water the whole year round, except of years of severe drought, because of the high groundwater level as well as the clay content of mostly > 5 percent.

9. TELEOST FISH DIVERSITY OF THE 'TSCHIFI DAIS'

Introductory, fish species in floodplain systems can be divided into two distinct groups on the basis of their behaviour in response to the conditions during the flood. The first group is comprised of riverine species which are total spawners (in one spawning) usually just prior or early in the flood and thus avoiding severe conditions on the floodplain by early migrating to the main channel. Some species are even confined to the main river channel at all times and never migrate on the floodplain. Species belonging to this group are *e.g. Alestes, Schilbe* and *Synodonthis*, whereas *Distichodus*, *Citharinus* and *Labeo* are more resistant (WELCOMME 1985).

The second group consists of species inhabiting the plain or vegetated fringes of the river channel during the dry season. They have prolonged spawning cycles (partial spawners) starting prior to the flood and often persisting to the peak flood. They are limited to lateral movements on the plain searching for permanent water bodies during the dry season. Species belonging to this group possess specific adaptation enabling them to survive under extreme conditions prevailing on the floodplain. Most siluroids together with clariids, ophiocephalids, anabantids, osteoglossids, polypterids and lungfish belong to this group (WELCOMME 1988).

At the beginning of the dry season many riverine species invading the large floodplain areas to spawn and breed are trapped in the 'Whedos' due to their failing to return into the river in time. However, this phase of relatively high species richness only rested for some months and rising mortality rates after the 'Whedos' isolation led to the decreased species richness found in all 'Whedos' at the end of the dry season.

9.1. DIVERSITY OF THE RIVERS AND THE 'WHEDOS' AND THEIR SEASONALITY

The Niger River crosses different climatic zones several times and thus fish communities are expected to change from section to section. According to FROESE & PAULY (2010), 260 freshwater fish species have been recorded for the entire Niger River. But MORITZ *et al.* (2006, 2007) assume that species richness increases towards the estuary and found 98 species at Malanville, with 17 species not yet recorded in the Middle Niger. Within our investigation we collected a total of 67 species belonging to 16 families (HAUBER *et al.* 2011a) in the River Niger. Although it represents only a proportion of fish species previously recorded by MORITZ, we could expand his inventory list by three species not yet recorded in the Middle Niger, thus resulting in 101 species (HAUBER *et al.* 2011b).

Table 5 gives an overview of the total species caught in the different 'Whedos' and the rivers, as well as the economically important species offered on the local fish market in Malanville. Fish sold on the market originate exclusively from the river fishery since fish caught in the 'Whedos' are usually sold on-site directly after the harvest.

As before, 'Whedos' have been classified as channel-flooded or river-flooded. However, the river-flooded 'Whedos' are further sub-divided as 'disconnected' (indicating they are isolated from the rivers during the dry season) and 'flooded' (inundated during the wet season). Twelve species could be found in 'Whedos' that are flooded directly by the rivers but seasonally isolated, whereas 15 species were collected in 'Whedos' connected with the rivers by irrigation channels. In total, 19 species from 12 families were recorded for the two types of 'Whedos' (HAUBER *et al.* 2011a). The most abundant were *Clarias gariepinus*, *Heterotis niloticus*, *Oreochromis niloticus* L., *Hemichromis* c.f. *letourneauxi*, *Polypterus senegalus* and *Epiplatys spilargyreius.*

With 36 species, the directly-flooded 'Whedos' investigated during the rainy season were more diverse and possess a similar species composition as the rivers (Fig. 18, P = 0.032, multiple mean value-comparison after KW-ANOVA; H = 16.72; N = 26, P = 0.0008). In contrast to DAGET (1954) and BLANC *et al.* (1955), who listed *Gymnarchus niloticus, Hepsetus* and *Parophiocephalus* as characteristic fauna of the Niger floodplain, we could not find any specimens of these three species in our study and interviews with fishermen revealed that species such as *G. niloticus* and *Parachanna obscura,* both highly appreciated as food fish, have almost disappeared from their fish landings, although they were previously abundant.

The species composition of channel-flooded 'Whedos' differed distinctly from that of the Niger and its tributaries as well as that of the 'Whedos' during flooding (HAUBER *et al.* 2011a).

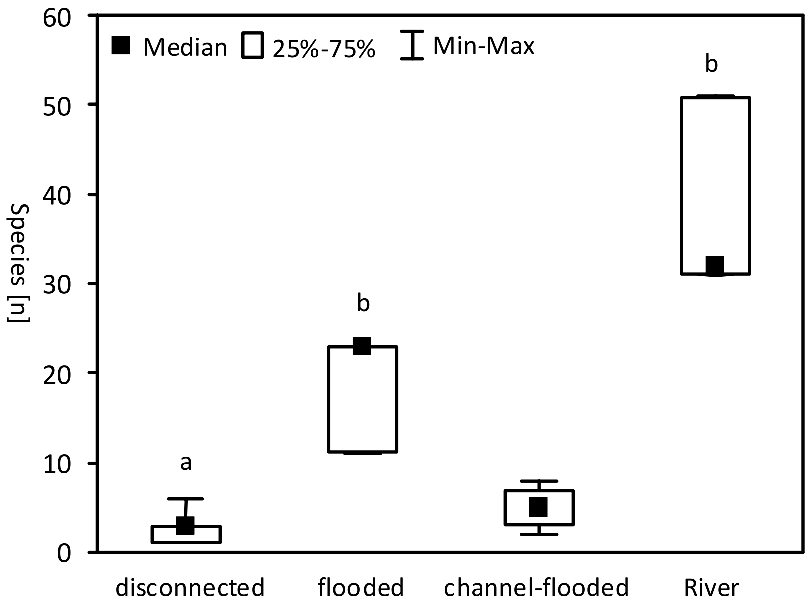


Figure 18: Species richness of the different types of 'Whedos' and the rivers.
Different letters indicate significant differences in mean species numbers.

However, during the dry season species composition of the previous flooded 'Whedos' was drastically reduced and thus very similar to the channel-flooded 'Whedos'. The species composition of both types of 'Whedos' expressed by the Jaccard-Index resembled each other strongly in MDS (Fig. 19).

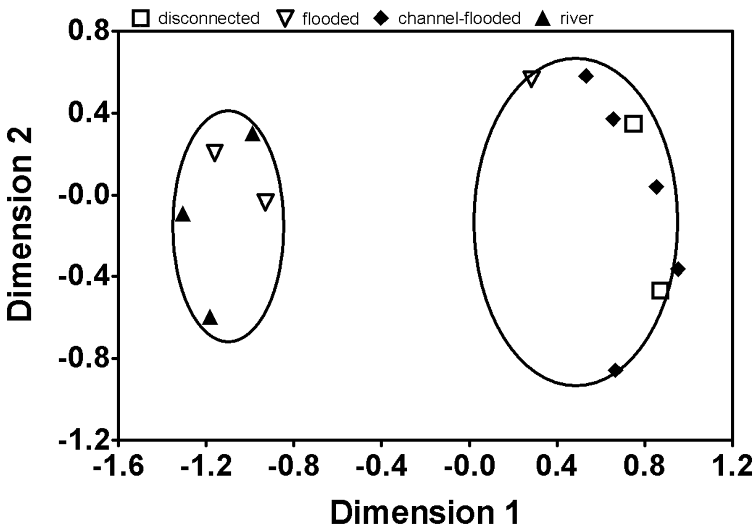


Fig. 19: MDS based on the species similarity of the investigated habitats calculated according to the Jaccard-Index; stress = 0.07.

Table 5: Detected fish species in different 'Whedos', the river channels and at the central market of Malanville.

Species		**'Whedos'**		**River**	**Market**	**Species**		**'Whedos'**		**River**	**Market**
	channel-flooded	disconnected	Flooded				channel-flooded	disconnected	flooded		
Protopteridae						**Citharinidae**					
Protopterus annectens	●	●			●	*Citharinus citharus*			●	●	●
Polypteridae						*Distichodus brevipinnes*			●	●	●
Polypterus endlicherii				●		*Distichodus rostatus*			●	●	●
Polypterus senegalus	●	●	●	●	●	*Paradistichodus dimidiatus*				●	
Osteoglossidae						*Neolebias unifasciatus*	●			●	
Heterotis niloticus	●	●			●	*Nannocharax ansorgii*				●	
Mormyridae						*Nannocharax fasciatus*				●	
Mormyrops rume				●		*Nannocharax lineomaculatus*				●	
Mormyrus marcophthalmus			●		●	*Nannocharax occidentalis*				●	
Mormyrops anguilloides				●		*Phago loricatus*				●	
Marcusenius senegalensis					●	**Cyprinidae**					
Brevimyrus niger		●		●	●	*Cheleathiops bibie*			●	●	
Pollimyrus isidori				●		*Leptocypris niloticus*			●	●	
Petrocephalus bovei				●		*Raiamas senegalensis*				●	
Petrocephalus soudanensis				●	●	*Barbus baudoni*			●	●	
Hippopotamyrus pictus				●		*Barbus bawkuensis*			●	●	
Clupeidae						*Barbus callipterus*			●	●	
Pellonulla leonensis			●	●		*Barbus hypsolepis*				●	
Alestiidae						*Barbus leonensis*				●	
Hydrocynus brevis			●			*Barbus macinensis*	●		●	●	
Hydrocynus vittatus			●	●		*Barbus macrops*			●	●	
Alestes baremoze					●	*Barbus prince*	●		●	●	
Alestes dentex			●	●	●	*Barbus punctitaeniatus*			●	●	
Brycinus leuciscus			●	●	●	*Barbus raimbaulti*				●	
Brycinus nurse			●	●	●	*Labeo senegalensis*			●		●
Brycinus macrolepidotus			●	●		*Labeo coubie*			●	●	●
Brycinus imberi				●		*Labeo parvus*	●			●	
Micralestes elongatus			●	●		**Bagridae**					
Rhabdalestes Db1				●		*Bagrus docmak*				●	
Rhabdalestes septentrionalis				●		*Bagrus bajad*					●

Table 5: Continued

Species	‘Whedos’ channel-flooded	‘Whedos’ disconnected	‘Whedos’ Flooded	**River**	**Market**
Claroteidae					
Clarotes laticeps					●
Chrysichthys auratus				●	●
Chrysichthys nigrodigitatus				●	●
Auchenoglanis occidentalis		●		●	●
Schilbeidae					
Parailia pellucida				●	
Siluranodon auritus			●		●
Schilbe intermedius			●	●	●
Clariidae					
Clarias anguillaris	●		●	●	
Clarias gariepinus	●	●	●	●	●
Hetreobranchus longifilis	●				●
Malapteruridae					
Malapterurus electricus					●
Malapterurus minjiriga					●
Amphiliidae					
Andersonia leptura				●	
Mochokidae					
Brachysynodontis batensoda			●	●	●
Hemisynodontis membranaceus				●	
Synodontis clarias					●
Synodontis macrophthalmus				●	
Synodontis nigrita				●	●
Synodontis ocellifer				●	●
Synodontis schall	●			●	●
Synodontis sorex					●
Synodontis velifer				●	
Synodontis Db2				●	

Species	‘Whedos’ channel-flooded	‘Whedos’ disconnected	‘Whedos’ flooded	**River**	**Market**
Cyprinodontidae					
Epiplatys spilargyreius	●	●	●	●	
Nothobranchius kiyawensis	●		●		
Fundulosoma thierryi			●		
Poeciliidae					
Micropanchax pfaffi				●	
Channidae					
Parachanna obscura		●			
Centropomidae					
Lates niloticus				●	●
Cichlidae					
Hemichromis cf. *letourneauxi*	●	●	●	●	
Hemichromis fasciatus					●
Oreochromis niloticus	●	●	●	●	●
Tilapia zillii			●	●	●
Sarotherodon galilaeus		●	●	●	●
Anabantidae					
Ctenopoma sp.		●			
Total	**15**	**12**	**36**	**67**	**39**

9.2 Influence of water parameters on fish diversity

As mentioned in chapter 9.1 there exists significant differences in species composition between the channel-flooded and river-flooded 'Whedos' during the rainy season, whereas their composition is very similar during the time of isolation at the end of the dry season meaning that river-flooded 'Whedos' exhibited a high species loss in the course of the year.

Through comparing diverse water parameters of the 'Whedos' and the rivers by KW-ANOVA, significant differences in DO concentrations (KW-H: 11.17; N = 19; P = 0.011) and conductivity (KW-H: 12.18; N = 19; P = 0.0068) were found (Fig. 20).

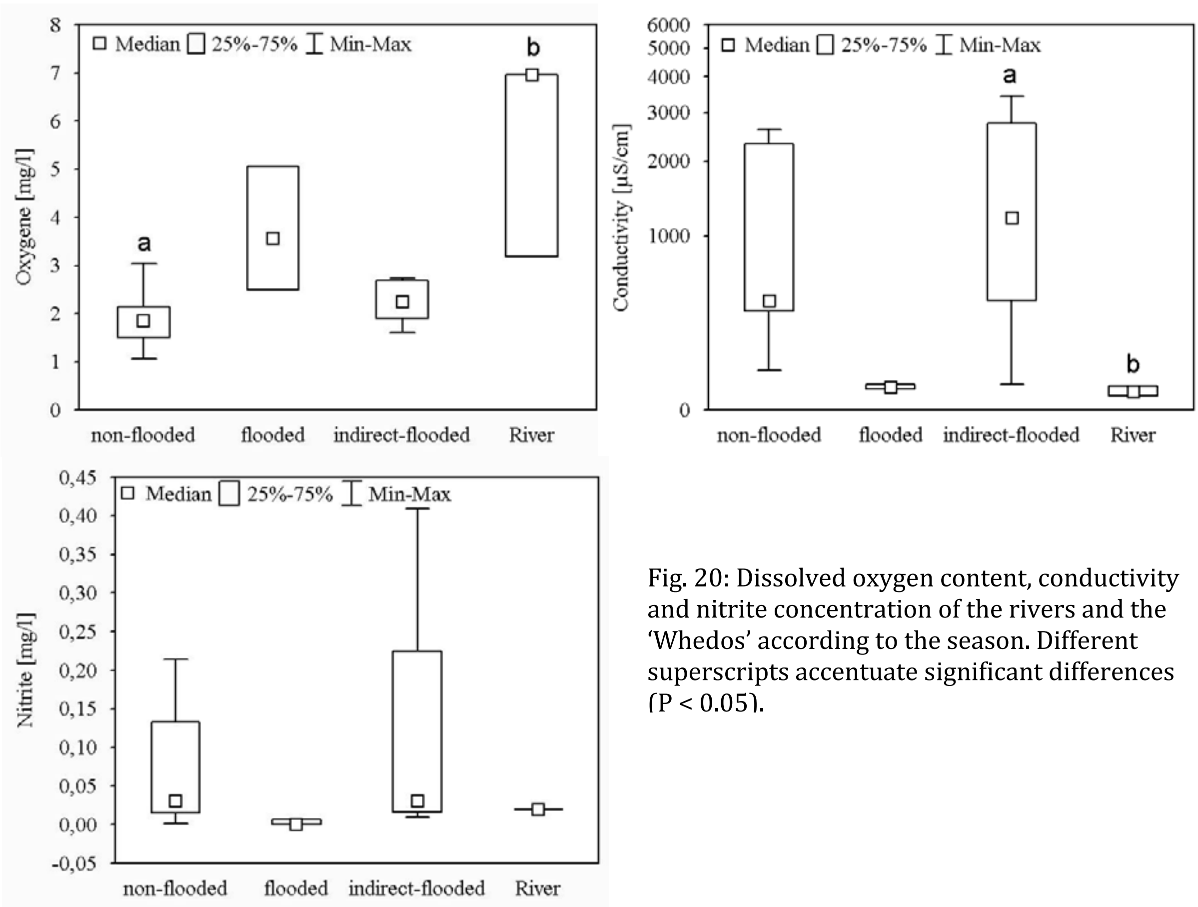


Fig. 20: Dissolved oxygen content, conductivity and nitrite concentration of the rivers and the 'Whedos' according to the season. Different superscripts accentuate significant differences (P < 0.05).

The rivers and the flooded 'Whedos' show higher oxygen levels than the channel-flooded and disconnected 'Whedos', but these differences are only significant between the rivers and the disconnected (isolated) pools (P = 0.02). Moreover, as a consequence of dilution effects conductivity was lower in flooded 'Whedos' and the rivers than in the disconnected and channel-flooded 'Whedos'. But these differences were only significant between rivers and channel-flooded 'Whedos' (P = 0.024). No significant differences existed between all waters in pH-values and temperature. Although nitrite concentrations was much higher in disconnected and channel-flooded ''Whedos'' than in the flooded ones and the rivers no significant difference could be found that is probably a result of the small sample size (Fig. 20). Consequently, channel-flooded and disconnected 'Whedos' suffer from low dissolved oxygen levels and high salt concentration (< 1 mg/L and > 4000 µS/cm, respectively, recorded for daily single values) as well as enormous nitrite levels (> 0.7mg/L) as a result of evaporation and desiccation. Therefore, we assume that differences in species composition and high mortality rate in the course of the dry season are the consequence of the unfavourable water quality. This assumption is also strengthened since surviving fish species are all adapted to low oxygen content (see chapter 9.4).

The lower species diversity in channel-flooded compared to river-flooded 'Whedos' might be the result of the adverse quality of the channel water additionally aggravated by man-made pollutants such as washing agents and mineral fertilizer from irrigation channels and rice fields causing an ecological barrier to fish species with a higher level of susceptibility to such environmental change. In addition, successful migration may be hindered by narrow channel entrances that restrict the access to the floodplain for breeders of migrating species.

9.3 Harvest of the 'Whedos'

Generally, final harvest is conducted once per year, mostly in March, at the end of the dry season. In some cases 'Whedos' are harvested completely on one single day, whereas others are harvested over a few days or even in weekly steps.

The seasonal differences in species composition and richness in 'Whedos' flooded during rainy season compared to their status at the end of the dry season are most obvious at final harvest. In the two river-flooded 'Whedos' with available data from all seasons, species richness was reduced by 64 % and 75 % (from 11 to 4 and from 24 to 6 species, respectively) at final harvest (Hauber *et al.* 2011c). At this time, the dominating species are *Clarias* spp. followed by *H. niloticus*, tilapian cichlids and some specimens of lungfishes and polypterids. Conspicuous is the dominance of only one genus (*Clarias* spp.) in almost all investigated 'Whedos' at this time of the year. In 10 out of the 16 investigated 'Whedos', *Clarias* spp. accounted for at least 90 percent of the total output (kg of total biomass harvested) (Tab. 6).

Moreover, artificial stocking of other species than *Clarias* did not significantly affect the overall biomass at final harvest. Nine 'Whedos' were additionally stocked by the farmers with *Tilapia* spp. (mostly *O. niloticus* and *S. galileus*) and riverine species of different size and density without removing *Clarias*. But these species were either not at all or only as single specimens present when harvesting these pools at the end of the dry season probably as a result of the interaction of predation and adverse water quality as well as deficient knowledge of the farmers on appropriate stocking practice.

Table 6: Harvest results of some 'Whedos' in 2008 and 2009 (dry season). Shown are the most abundant species as a percentage of the total biomass (kg) harvested. Some notes are given if and what kind of species were additionally stocked.

'Whedo'	Type	Total biomass (kg)	Species in Catch (%)				Artificially stocked
			***Clarias* spp.**	***Heterotis niloticus***	**Cichlids**	**Others**	
			2008				
Noma Idé 1	fl/dc	88,5	100.0	0.0	0.0	0.0	*Clarias, Tilapia*
Noma Idé 2	fl/dc	87,0	97.4	0.0	1.7	0.9	
Damatabi Nsidou	fl/dc	449.3	99.6	0.0	0.0	0.4	*Tilapia*
Gounai Windi	fl/dc	164,0	93.9	6.1	0.0	0.0	
Lakalikanei 1	fl/dc	562,9	92.0	0.0	6.7	1.4	
Lakalikanei 2	fl/dc	8,75	66.3	0.0	12.6	21.2	
DagaraMama	ch-fl	6.8	87.5	11.8	0.7	0.0	*Clarias, Tilapia*
Macheresse	ch-fl	14.75	38.6	27.1	29.8	4.5	*Heterotis, Tilapia*
			2009				
Damatabi Nsidou	fl/dc	171.95	90.8	7.6	0.0	1.6	*Tilapia*
Noma Idé 1	fl/dc	108	100.0	0.0	0.0	0.0	*Clarias, Tilapia*
Noma Idé 2	fl/dc	99.35	99.6	0.0	0.0	0.4	
GoroBani	fl/dc	486.9	89.6	0.0	9.0	1.4	
MamaMassou	fl/dc	137.05	86.5	0.0	13.5	0.0	*Clarias, Tilapia*
MourouWindi	fl/dc	359.12	98.9	0.0	1.1	0.0	
BotchoManou	ch-fl	39	99.0	0.0	0.4	0.6	*Clarias, Tilapia*
Macheresse	ch-fl	410.55	24.8	18.0	56.8	0.4	*Heterotis, Tilapia*

fl/dc = river-flooded disconnected; ch-fl = channel-flooded.

Because of its stocking management and probably its comparatively large dimension (> 7000 m^2), only the 'Whedo' Macheresse did not show this overwhelming presence of *Clarias* spp. Exceptional, in this channel-flooded 'Whedo', small and medium sized tilapian cichlids and *Heterotis* were thrown back into the pool for further growing after final harvest, whereas *Clarias* spp. of all sizes were taken out of the pond to prevent predation. Indeed, this stocking management lead to the fact that other species than *Clarias* are also abundant in the 'Whedos', but all of them possessing adaptations to low oxygen concentrations. Riverine or susceptible species are still missing, thus highlighting apart from predation the importance of the water quality.

9.4 Adaptation of 'Whedo'-dwelling fish

Species enduring the dry season in the 'Whedos' have specific anatomical or physiological adaptation enabling them to survive deoxygenation, high temperatures and even desiccation (Welcomme 1979). At this time most abundant species were *Clarias gariepinus*, *Heterotis niloticus*, *Polypterus senegalus* and *Epiplatys spilargyreius* as well as *Oreochromis niloticus* L. and *Hemichromis* c.f. *letourneauxi* although they are defined as occasional swamp-dwelling species by the FAO/UN (1971). Additionally, *Protopterus annectens, Brevimyrus niger, Auchenoglanis occidentalis, Ctenopoma* sp. and *Sarotherodon galilaeus* could be frequently detected at the end of the dry season.

In our study, from the 19 species found in disconnected and channel-flooded 'Whedos' 14 are known for their adaptations to low oxygen levels by using either the oxygen-rich layer of the water surface (*O. niloticus*, *S. galileus*, *Synodontis* spp. Bénech & Lek 1981; Killifishes Lewis 1970 and Kramer & McClure 1982) or atmospheric air (*H. niloticus* Lüling 1977; *P. senegalus*, *P. annectens*, *Clarias* spp. Welcomme 1979; *Brevimyrus niger* Moritz & Linsenmair 2007). Worth noting is the occurrence of *Brevimyrus niger* in isolated 'Whedos' with oxygen levels of about 1 mg/L, thus supporting the findings of their air breathing behaviour by Moritz & Linsenmair (2007). All other representatives of this family were found either directly in the river or in flooded 'Whedos' with much higher oxygen levels.

Apart from adaptation to deoxygenated conditions, some species, such as cichlids and catfishes, are known for their euryhalinity enabling them to withstand high salt concentrations (Eddy *et al*. 1980; Foskett *et al.* 1981; Whitfield & Blabber 1976). Also *Synodontis schall,* recorded in channel-flooded 'Whedos', belong to the group of euryhaline freshwater species (Welcomme 1988). Additionally, *Clarias* and *Protopterus* (African lung fish) are able to survive desiccation of the 'Whedos' in years of extreme drought by cocooning or taking refuge in soft mud, respectively (Welcomme 1979), whereas *Epiplatys spilargyreius* are able to maintain population in desiccating habitats because of several adaptations including drought resistant dormant eggs and fast hatching responses to rainfall (Welcomme 1985).

Another important adaptation in order to avoid adverse conditions on the floodplain is the different migration habit of fish species. Therefore, species sensitive to deoxygenation, such as *Alestes sp.* and *Labeo senegalensis,* leave the plain earlier at the draw-down period, whereas more resistant species such as *Clarias sp*. leaves the floodplain later (DAGET 1957), giving a further explanation why they are more abundant in the 'Tschifi dais'. Generally, depths, dissolved oxygen and temperature are most likely the major stimuli determining return migration of fish species meaning the time they are leaving the floodplain. Nevertheless, it seems that these stimuli are not always effective and also a fast drop of the water level might impede their return migration since stranding or isolation of fish in temporary pools is probably the greatest single reason of mortality in flood-rivers (WELCOMME 1988; WINEMILLER & JEPSEN 1998).

Finally, floodplain-dwelling fish have to maintain maximum flexibility in their food use and thus the degree of physical specialisations is quite low. Most species can be classified as omnivores or generalized-micro predators and bottom deposits represent the most common alternative food source (WELCOMME 1988). The high abundance of *Clarias* is possible due to their generally carnivorous but also indiscriminate feeding habit (DE GRAAF & JANSSEN 1996; GROENEWALD 1964); *H. niloticus, P. annectens* and *P. senegalus*, found in most 'Whedos', are also predators (GOSSE 2003). This species composition is in agreement with LOWE-MCCONNELL (1964) and WELCOMME (1979) recording that crowding at the end of the dry season led to a high proportion of predators in floodplain pools.

9.5. NEW RECORDS OF FISH SPECIES IN THE RIVER NIGER AT MALANVILLE (NORTH-EAST BENIN)

The study concentrated on the Middle-Niger at Malanville (North-East-Benin), 1,130 km upstream of the estuary, respectively 3,050 km downstream from the sources of the Niger (MORITZ *et al.* 2006) and on one of its branches and the river Sota; a tributary with a length of 250 km flowing into the Niger at Malanville (VAN DEN BOSSCHE & BERNACSEK 1990) (Fig. 21). According to FROESE & PAULY (2010), 261 freshwater fish species are recorded for the river Niger.

However, the Niger is crossing different climatic zones several times and thus fish communities are expected to change from section to section. MORITZ *et al.* (2006) assumed that species richness increases towards the estuary. Up to now, 98 species belonging to 22 families are recorded for the Middle-Niger (LAË *et al.* 2004). However, MORITZ *et al.* (2006) found 98 species at Malanville, but with 17 formerly not yet recorded species for this part of the river. With the recent study we want to complement the annotated list of fishes from the River Niger published by MORITZ *et al.* (2006) in the "*Verhandlungen der Gesellschaft der Ichthyologie Band* 5".

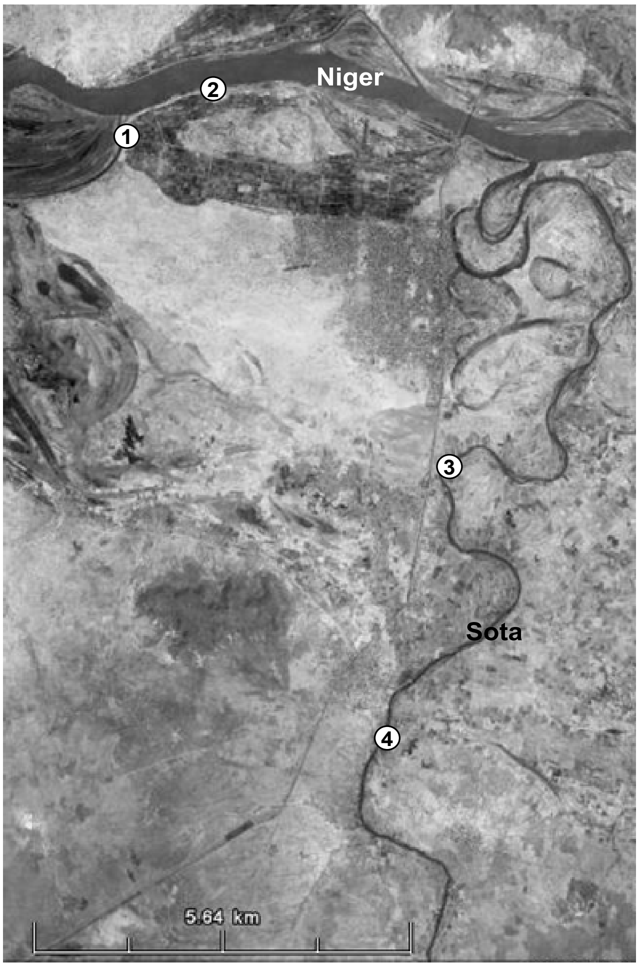


Fig. 21: Location of the different study sites around Malanville (North-East Benin). 1 = Branch of the river Niger; 2 = River Niger, (the black spot illustrates the rice perimeter situated along the river); 3 + 4 = River Sota.

Sampling was conducted from June to September 2008 by using a small seine (2m*1m, mesh size 5mm, see MORITZ *et al.* (2006)) as well as setting gill nets (30-40m*0.5-1.5m; MS 25-50mm) overnight. Each habitat was sampled not less than four times. Water chemistry was measured simultaneously by analysing water taken at a depth of 20 cm from the surface between 7.30h and 12.00h. Results are listed as mean values in Table 7.

Water temperature (°C) and oxygen concentration were measured with DO-100 from Voltacraft (accuracy ± 0.4 mg/l), while conductivity and pH-value were analysed applying the HI98129 Combo from Hanna (accuracy ± 1µS/cm or 0.01, respectively).

Calibrations were conducted according to the manufacturer's recommendations. Nitrite, nitrate, ammonia as well as total phosphorus (P) concentrations (all measured in mg/L) were analysed with the help of colorimetric test kits (Macherey-Nagel).

In total we collected 67 species belonging to 16 families (see HAUBER *et al.* 2011b), thus representing only a proportion of fish species already recorded by MORITZ *et al.* (2006). Nevertheless, for three species distribution gaps could be closed and for further three species their already known distribution could be expanded:

Polypteridae: *Polypterus endlicheri endlicheri* Heckel, 1849 with a standard length (SL) of 325 mm was captured in the Sota. The discovery of this species in a tributary of the Niger proves the expected but hitherto not verified occurrence of this species (MORITZ *et al.* 2006; MUREI *et al.* 2003). So far it was only recorded for the Kainji Reservoir and the Niger delta (PAUGY *et al.* 2003a).

Tab. 7: Water parameters of the different river channels measured from June to September 2008. If possible data are presented as mean values and their standard error of the mean.

	Niger	Niger Branch	Sota
Temp. (°C)	28,4 (±1.3)	29,3 (±1.4)	28,0 (±1.8)
DO (mg/l)	6,7 (±0.9)	3,1 (±0.5)	6,4 (±0.8)
pH	6,7 (±0.3)	6,7 (±0.4)	6,64 (±0.3)
EC (µS/cm)	63 (±12.5)	70 (±12.2)	53 (±15.3)
TH (°dH)	3 (±0)	3 (±0.6)	2 (±0)
CH (°dH)	2 (±0)	3 (±0.6)	2 (±1.4)
NH_4 (mg/l)	0 (±0)	0 (±0)	0 (-)
NO_3 (mg/l)	5 (±0)	12 (±2.9)	5 (-)
NO_2 (mg/l)	0,02 (-)	0,02 (±0)	0,02 (-)
P (mg/l)	0 (-)	0 (±0)	0 (-)
SDD (cm)	7 (±4.7)	16 (±11)	16 (±8.9)

Temp. = Water temperature; DO = Dissolved oxygen; EC = Electric conductivity; TH = Total hardness measured as 'deutsche Härte'; CH = Carbonate hardness measured as 'deutsche Härte'; P = Total phosphorous; SDD = Secchi Disc Depth.

Distichodontidea: With the record of *Neolebias unifasciatus* Steindachner, 1894 another distribution gap was closed (Fig. 22D). This species was only known from the Inland Delta of the Niger and its estuary into the Atlantic Ocean and has not yet been found in the Middle Niger (GOSSE & COENEN 2003). We found two specimens with 25.9 mm and 24.6 mm SL in the Niger branch and the Sota, respectively.

The high species richness of the genus *Nannocharax* around Malanville was already mentioned by MORITZ *et al.* (2006). However, the recent study detected one more species, *N. ansorgii* Boulenger, 1911 (35.5 mm SL) which has so far not been found in the river Sota (Fig. 22C) (GOSSE & COENEN 2003). Another remarkable observation was one specimen of *N. fasciatus* that carried eggs adherent at all fins except the adipose.

Cyprinidae: To the inventory list of the genus *Barbus* presented by MORITZ *et al.* (2006) for the Niger at Malanville the species, *B. bawkuensis* Hopson, 1965 has to be added. Up to now, *B. bawkuensis* is only known from the Volta and the Sokoto, a tributary of the Niger and has never been found so far north (LÉVÊQUE 2003). We recorded numerous specimens in river sites with SL ranging from 16.5 to 28.8 mm.

Mochokidae: MURAI *et al.* (2003) already stated the occurrence of *Synodontis macrophthalmus* Poll, 1971, but the given photograph shows, according to MORITZ *et al.* (2006), *S. sorex*. *S. macrophthalmus* is recorded from the type locality, at Ampem, Volta basin in Ghana (PAUGY *et al*. 2003b), but its distribution can be extended to the river Sota.

Fig. 22: Life colouration of fish species recorded around Malanville: A *Brycinus leuciscus*, B *Brycinus leuciscus* (red adipose), C *Nannocharax ansorgii*, D *Neolebias unifasciatus*.

Alestidae (formerly Characidae): Numerous specimens of *Brycinus leuciscus* Günther, 1867 were caught in all the river sites with a SL ranging from 5.38 to 50.7mm (Fig. 22A). As already observed by MORITZ (personal communication), some individuals showed a clear reddish coloration of the dorsal adipose fin instead of the described yellowish appearance (Fig. 22B) (PAUGY *et al*. 2003a). Further studies are needed to clarify if this coloration is just a local variation or if it is a new subspecies.

The typical morphological and habitus characteristics of the species listed above are well defined in for example PAUGY *et al.* (2003a, 2003b), and therefore are not further defined here. The specimens are now deposited at the Goethe University Frankfurt (Germany).

10. DISCUSSION

In regard to the study focussing on the fish diversity the investigations found species compositions to differ distinctly between disconnected dry season pools and the same pools during the flooding period. The strong reduction in species richness during dry season is probably a result of decreasing water quality, especially due to low oxygen and high salt concentration. This assumption is underlined by the fact that most species found in disconnected pools possess either accessory breathing organs or are able to use aquatic surface respiration enabling them to survive extreme water conditions. These results show that permanent floodplain pools can serve as refuges for fish adapted to harsh water conditions. But, water quality might not be the only factor determining fish diversity in 'Whedos' and future investigations should determine the role of predators, especially *Clarias* spp. and other possible reasons, *e.g.* natural food limitation.

Interestingly, channel-flooded pools resembled disconnected 'Whedos' strongly. This might be due to disturbed migration feasibility since channel entrances spatially restrict the access to the floodplain for migrating species. Further studies should clarify if biomass production in these two 'Whedo' types differs significantly and how irrigation channels may negatively affect migration.

11. RECOMMENDATIONS

11.1 MAINTENANCE OF THE FISH HOLES

As a matter of course it is crucial to improve or maintain the water quality in order to suit the requirements of the respective species and also to provide conditions for optimal growth and survival. In this sense, fish farmers should make some efforts to increase the transparency of the water that is essential for primary production (phytoplankton growth) and thus the dissolved oxygen concentration of the 'Whedos'. The physical structure must be maintained and thus it is important to prevent livestock walking on pond embankments or wading in the shallows because it might cause the erosion of the banks. Moreover, embankments should be covered with grass or other plants to reduce erosion by rain and wind.

The oxidized layer, the intermediate between the pond water and the soil sediment, plays a crucial role in oxidizing toxic metabolites such as hydrogen sulphide (H_2S), to non-toxic forms by chemical and biological activity while passing through the aerobic surface layer of the pond bottom (BOYD *et al*. 2002, 2002b). Fish die-off can occur in ponds with knee-high bottom mud after the onset of the first rains accompanied with strong winds causing turbulence in the ponds bringing hydrogen sulphide to the surface.

Thus, it is essential to prevent the accumulation of organic matter at the bottom that would increase the consumption of dissolved oxygen (DO) through its decomposition by microorganism and thus encourage anaerobic conditions at the sediment water interface. Soft sediment and mud at the pond bottom should also be removed regularly preventing its dispersion by bottom feeding fish *e.g. Clarias*. A relatively easy method for the farmers to check for anaerobic conditions is to monitor the appearance of the soil. If the upper few centimetres of the bottom soil show a gray or black colour reduced conditions are likely. Removal of the bottom mud should therefore be conducted after the final harvest at the end of the dry season when the water level is already drastically reduced through evaporation as well as the operation of motor pumps. Other practical reasons for sediment removal are the potential loss of pond volume, soft sediments trapping feed and the obstruction of seining operations.

Macrophytes also affect the oxygen content of the 'Whedos'. Therefore, except of a small batch serving as shelter for the fish, the regular removal of macrophytes covering the water surface and growing along the embankments is of high importance in maintaining aerobic conditions.

11.2. Potential management strategies

Several times it could be observed that farmers are lacking knowledge, thus constructing their 'Whedos' on sites that are not appropriate because of highly sandy soils, too low groundwater table or construction outside the floodplain leading to their desiccation during the dry season as well as contaminated run-off water entering from the polluted surrounding. Therefore, it is essential to guarantee technical support to the farmers at the very beginning to prevent the failure of the 'Whedo'-system that would lead to increasing resentment.

Generally, nitrogen fixation in the soil is an important source of N in many ponds making fertilization unnecessary. As a consequence of their high sand content the soils are generally rated low in total nitrogen. N reserves in the form of ammonium cation absorbed at exchange sites in the pond bottom are low but nevertheless nitrogen concentration of the water are in the range recommended for aquaculture. Since, the majority of nitrogen of the water originates from allochthonous resources (*e.g*. dung and run-off) or fish faeces rather than from the soil, nitrogen concentration should be regularly analysed and if required the 'Whedos' should be fertilized. One possible material serving as fertilizer might be rumen content available at the local slaughterhouse in Malanville. The advantages are that the rumen content is free of charge and farmers are inured to its use since they already apply it on their rice fields. However, fertilization aimed at improving the N supply should always consider the C:N ratio, that is quite low for the 'Tschifi-dais', to avoid the risk of anaerobic conditions.

Moreover, it could be beneficial to apply agricultural limestone or other means to increase soil pH and therewith the concentrations of alkalinity and total hardness of the pond water. Liming of the pond may enhance conditions for productivity of food organisms and increase aquatic animal production. Liming is especially advisable in freshwater pond with alkalinity concentrations below 40 or 50 mg/L or with soil pH below 7 (BOYD & TUCKER, 1998).

As already mentioned, the water quality prevailing in the 'Whedos', especially during the dry season, represents the major obstacle. Fish species used for cultivation have to be adapted to these adverse conditions and thus the choice is restricted to floodplain-dwelling species that are able to survive under deoxygenation and high temperature. Furthermore, in order to provide them with sufficient food and achieve satisfactory growth rates, the cultured species should be omnivores.

Since 'Whedos' suffer from a high fish mortality in the course of the dry season, one way to increase productivity directly might be the introduction of a second harvest shortly after the end of the flood when pools become isolated from the river system. This would enable the farmers to catch trapped riverine species (first harvest), which cannot tolerate the progressively deteriorating water quality after the pools become isolated. This would be followed at the usual harvest time when many clariids are caught (second harvest). Small *Clarias* caught during the first harvest should be restocked and fed with cheap locally available by-products to increase their growth rate until traditional harvest at the approach of the rainy season takes place.

The change of the species composition in most of the 'Whedos' from a diverse riverine community during the flood to a highly *Clarias*-dominated one at the end of the dry season should be kept in mind when stocking the 'Whedos'. According to our observations an artificial stocking of tilapian cichlids and other riverine fish by the fish farmers did not result in any economical benefit. The final harvest in terms of number of fish species and biomass did not differ in comparison to 'Whedos' receiving their fishes only via inundation. This shows that farmers need training to improve their knowledge of practical stocking strategies such as the appropriate species, size, density and ratio of fish to be stocked as well as basic knowledge of management to avoid the waste of capital and labour.

12. CONCLUSION

The fast demographic growth (4.8 percent on an average 1992 to 2000 (ADJOVI 2006)) of the commune of Malanville is also reflected in increased demand for food; thus one challenge is and will be the search for alternatives to increase overall food security. The management of the 'Whedos' is an attractive system for the rural population because of existing knowledge of post-flood wetland fisheries *e.g*. fishing in marshes and natural depressions in the floodplain, as well as the low investment needed for its installation.

But despite the fast development of the 'Whedo'-aquaculture-system, the management of the 'Tschifi dais' leaves a lot to be desired. So far, the majority of the farmers do not take responsibility for their fish holes apart from the initial construction and annual harvest particularly because of their lack of knowledge. Only a few are providing additional feed or maintaining their 'Whedos' through the removal of the bottom mud and macrophytes covering the water surface. Some of the prevailing conditions represent obstacles for aquaculture activities and thus have to be considered in planning to increase the probability of a successful outcome.

However, although permanent pools might increase the survival rate of some fish species during the dry season further studies are needed to clarify whether increasing 'Whedo' construction might transform the nature of the floodplain in a way which will negatively affect its fish community and biodiversity.

13. REFERENCES

ADHIKARI, S. 2003. Fertilization, soil and water quality management in small-scale ponds: Fertilization requirements and soil properties. *Aquaculture Asia* 8 (4): 6-8.

ADJOVI, A.R. 2006. Monographie de la commune de Malanville. Programme d'appui au démarrage des communes. Mission de décentralisation (Afrique conseil). p. 48.

AGOSSOU, G. 2001. Influence des pratiques de maîtrise de l'eau pour l'agriculture sur certains déterminants de la sécurité alimentaire: Etude du cas de la zone de l'Extrême-Nord du Bénin. Thèse de DEA. Université du Bénin. Faculté des Lettres, Arts et Sciences Humaines. p. 79.

ALAM, A. & AL-HAFEDH, Y.S. 2006. Diurnal dynamics of water quality in an aquaculture system based on recirculating green water technology. *J. Applied. Sci. Environ. Mgt.* 10 (2): 19-21.

ALLAN, J. D., ABELL, R., HOGAN, Z., REVENGA, C., TAYLOR, B.W., WELCOMME, R.L. & WINEMILLER, K. 2005. Overfishing of Inland Waters. *BioSciences* 55 (12): 1041- 1050.

ANDERSEN, I., DIONE, O., JAROSEWICH-HOLDER, M. & OLIVRY, J.-C. 2006. The Niger River basin: A vision for sustainable management. K. G. GOLITZEN (ed.). The World Bank. Washington, DC. p. 144.

AREGHEORE, E.M. 2006. Country Pasture/Forage Resource Profiles. The Republic of Benin. Online Document: http://www.fao.org/ag/AGP/AGPC/doc/Counprof/Benin/Benin.htm

BENECH, V. & LEK, S. 1981. Résistance à l'hypoxie et observations écologiques pour seize espèces des poissons du Tchad. *Rev. Hydrobiol. Trop.* 14: 153-168.

BLANC, M., DAGET, J. & D'AUBENTON, F. 1955. Recherches hydrobiologiques dans le bassin du Moyen-Niger. *Bull. Inst. Fr. Afr. Noire (A. Sci. Nat.)* 17: 619-746.

BOWMAN, J.R. & LANNAN, J.E. 1995. Evaluation of Soil pH-Percent Base Saturation Relationships for Use in Estimating the Lime Requirements of Earthen Aquaculture Ponds. *Journal of the World Aquaculture Society* 26 (2): 172-182.

BOYD, C.E. & MUNSIRI, P. 1996. Phosphorus adsorption capacity and availability of added phosphorus soils from aquaculture area in Thailand. *Journal of the World Aquaculture Society* 27 (2): 160-167.

BOYD, C.E. & BOWMAN, J.R. 1997. Pond bottom soils. Pp. 135-162 *In* EGNA H.S. & BOYD C.E. (eds.). Dynamics of Pond Aquaculture. CRC Press LLC, USA. p. 437.

BOYD, C.E. & TUCKER, C.S. 1998. Pond aquaculture water quality management. Kluwer Academic Publishers, Boston, Massachusetts. p. 700.

BOYD, C.E., WOOD, C.W. & THUNJAI, T. 2002. Aquaculture pond bottom soil quality management. Pond dynamics/Aquaculture Collaborative Research Support Program. Oregon, USA.

BOYD, C.E., WOOD, C.W. & THUNJAI, T. 2002b. Pond soil characteristics and dynamics of soil organic matter and nutrients. Pp. 1-10 *In* K. MCELWEE, K. LEWIS, M. NIDIFFER & P. BIUTRAGO (eds.). Nineteenth Annual Technical Report. Pond dynamics/Aquaculture CRSP, Oregon State.

BREUIL, C. & QUENSIERE J. 1995. Eléments d'une politique de développement durable des pêches et de la pisciculture en Mali. MLI/91/005-PAMOS. FAO, Rome. p. 89.

BUTTNER, J.K., SODERBERG, R.W. & TERLIZZI, D.E. 1996. An introduction to water chemistry in freshwater aquaculture. North-eastern Regional Aquaculture Center, Fact Sheet No. 170. University of Massachusetts, Dartmouth.

CIFA 1990. Source book for the inland fishery resources of Africa Vol. II. Technical Paper (18) 2. FAO, Rome.

COENEN, E. 1986. Résultats des études ichthyo-biologiques sur le Niger. Projet Développement des Pêches, Ner/79/018.

DAGET, J. 1954. Les poisons du Niger Supérieur. Mémoires Inst. Fr. Afr. Noire, 36. p. 391.

DAGET, J. 1957. Mémoires sur la biologie des poisons du Niger moyen. Part 3. Reproduction et croissance *d'Heterotis niloticus* Ehrenberg. *Bull. Inst. Fr. Afr. Noire* 19: 295-323.

DE GRAAF, G. & JANSSEN, J. 1996. Handbock on the artificial reproduction and pond rearing of the African catfish *Clarias gariepinus* in sub-saharan Africa. Fisheries Technical Paper 362, Nefisco Foundation, Amsterdam, the Netherlands, FAO, Rome.

DENNY, P. 1985. Wetland vegetation and associated plant life-forms. Pp. 1-18 *In* P. DENNY (ed.). The ecology and management of African wetland vegetation. Dr. W. JUNK Publishers, Dordrecht.

DOSSOU, S. 2008. Etudes des potentialités et des contraintes de développement de la pisciculture dans la commune de Malanville au Bénin. Thèse de DEA. Université d'Abomey-Calavi, Bénin. Faculté des sciences agronomiques. p. 83.

DUNLOP, J., MCGREGOR, G. & HORRIGAN, N. 2005. Potential impacts of salinity and turbidity in riverine ecosystems. Characterisation of impacts and a discussion of regional target setting for riverine ecosystems in Queensland. State of Queensland.

EDDY, E.S., BAMFORD, O.S. & MALOIY, G.M.O. 1980. Sodium and Chloride balance in the African Catfish *Clarias mossambicus*. *Comparative Biochemistry and Physiology Series* 66A: 637-641.

FAO/UN 1971. Rapport au Gouvernement du Dahomey sur l'évolution de la pêche intérieure, son état actuel et ses possibilités, établi sur la base des travaux de R. L. WELCOMME, Spécialiste de la pêche, Rapport FAO/PNUD(AT) 2938. p. 97.

FAO (Food and Agriculture Organization of the United Nations).

_____ 1972. Kainji Lake Research Project, Nigeria. Fish populations of Kainji Lake, trends in their development and utilization, Based on the work of A. LELEK. Rome, FAO, FI:SF/NIR 24, Technical Report No 2. p. 121.

_____ 2009a. Calculated from food balance sheets. FAOSTAT Online request: http:faostat.fao.org/site/368/DesktopDefault.aspx?PageID=368#ancor. Accessed January 2010.

_____ 2009b. Low-income food-deficit countries 2009. FAO country profiles. Online request: http://www.fao.org/countryprofiles/lifdc.asp. Accessed November 2009.

FOSKETT, J.K., CRAIG, D.; LOGSDON, D.; TURNER, T.; MACHEN, T.E. & BERN, H.A. 1981. Differentiation of the Chloride extension mechanism during seawater adaptation of a teleost fish, the Cichlid *Sarotherodon mossambicus*. *Journal of Experimental Biology* 93: 209-224.

FROESE, R. & PAULY, D. 2010. Fishbase. World Wide Web electronic publication. www.Fishbase.org; Accessed January 2011.

GEC (Grassetti Environmental Consulting) 2008. Draft Environmental Impact Report - Dutch Slough Tidal Marsh Restoration Project. http://www.dutchslough.org/homepage.html

GOSSE, J.-P. & COENEN, E. J. 2003. *Distichodontidae*. Pp. 237-260 *In* D. PAUGY, C. LÉVÊQUE & TEUGELS G.G. (eds.). Faune des poissons d'eaux douces et saumâtres de l'Afrique de l'Ouest. Tome 1. Collection Faune et Flore tropicales 40. IRD, Paris.

GROENEWALD, A.A. v. J. 1964. Observation on the Food Habits of *Clarias gariepinus* Burchell, the South African Freshwater Barbel (Pisces: Clariidae) in Transvaal. *Hydrobiologia* 23 (1-2): 287-291.

gtz 2002. Back to Basics. Traditional Inland Fisheries Management and Enhancement Systems in Sub-Saharan Africa and their Potential for Development. Universum Verlagsanstalt, Wiesbaden, Germany.

HART, B.T., BAILEY, P., EDWARDS, R., HORTL, K., JAMES, K., MCMAHON, A., MEREDITH, C. & SWADLING, K. 1991. A review of the salt sensitivity of the Australian freshwater biota. *Hydrobiologia* 210: 105-144.

HAUBER, M., BIERBACH, D. & LINSENMAIR, K. E. 2011a. A description of teleost fish diversity in floodplain pools ('Whedos') and the Middle-Niger at Malanville (North-eastern Benin). Journal *of Applied Ichthyology* 27: 1-5.

HAUBER, M., BIERBACH, D. & LINSENMAIR, K. E. 2011b in press. New records of fish species in the River Niger at Malanville (North-East Benin). *Bulletin of Fish Biology*.

HAUBER, M.E., BIERBACH, D. & LINSENMAIR, K.E.L. 2011c. The Traditional 'Whedo' Aquaculture System in Northern Benin. *Journal of Applied Aquaculture* 23 (1): 67-84.

HEJNY, S. 1960. Ökologische Charakteristik der Wasser- und Sumpfpflanzen in den slowakischen Tiefebenen (Donau- und Theissgebiet). Bratislava.

HENRY-SILVA, G.G., CAMARGO A.F.M. & PEZZATO M.M. 2008. Growth of free-floating aquatic macrophytes indifferent concentrations of nutrients. *Hydrobiologia* 610: 153-160.

IUCN/SSC Invasive Species Specialist Group 2010. Global invasive species data base: http://www.issg.org/database/species/search.asp?st=100ss

JOHN, D.M. 1986. The inland waters of tropical West Africa. An introduction and botanical review. Archiv für Hydrobiologie: Ergebnisse der Limnologie 23. p. 244*.*

KRAMER, D.L. & MCCLURE, M. 1982. Aquatic surface respiration, a widespread adaptation to hypoxia in tropical freshwater fishes. *Environmental Biology of Fish* 7: 47-55.

LAË R. 1992. Influence de l'hydrobiologie sur l'évolution des pêcheries du delta centrale du Niger, de 1966 à 1989. *Aquatic Living Resources* 5: 115-126.

LAË R. 1995. Climatic and anthropogenic effects on fish diversity and fish yields in the central delta of the River Niger. *Aquatic Living Resources* 8: 43-58.

LAË R., WILLIAMS S., MORAND P. & MIKOLASEK O. 2004. Pp. 199-277 *In* R. WELCOMME & PETR T. (eds.). Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries: Sustaining livelihoods and biodiversity in the new millennium, Vol. I. FAO, Rome. International symposium on the management of large river for fisheries 2, 2003-02-11/2003-02-14. Phnom Penh, Cambodge.

LALEYE, P., AKELE, D. & PHILIPPART, J.C. 2007. La pêche traditionnelle dans les plaines inondables du fleuve Ouémé au Bénin. *Cahier d'Ethologie* 22 (2): 25-38.

LEVEQUE, C. 2003. Cyprinidae. Pp. 269-361 *In* PAUGY, D., LEVEQUE, C. & TEUGELS, G. G. (eds.). Faune des poissons d'eaux douces et saumâtres de l'Afrique de l'Ouest. Tome 1. Collection Faune et Flore tropicales 40. IRD, Paris

LEWIS, W. M. 1970. Morphological adaptations of cyprinodonts for inhabiting oxygen deficient waters. *Copeia* 2: 319-326.

LOWE-MCCONNELL, R. H. 1964. The fishes of the Rupununi savanna district of British Guiana, South America. Part 1. Ecological groupings of fish species and effects of the seasonal cycle on the fish. *J. Linn. Soc.* 45: 103-144.

LÜLING, K.-H. 1977. Die Knochenzünglerfische. A. Ziemsen Verlag, Wittenberg.

MORITZ, T., LALÈYÈ, P., KOBA, G. & LINSENMAIR, K.E. 2006. An annotated list of fish from the River Niger at Malanville, Benin, with notes on the local fisheries. *Verhandlung der Gesellschaft für Ichthyologie* 5: 95-110.

MORITZ, T. & LINSENMAIR, K.E. 2007. The air breathing behaviour of *Brevimyrus niger* (Osteoglossomorpha, Mormyridae). *Journal of Fish Biology* 71: 279-283.

MUREI, T., DEGBEY, J.-B., & C. HOUNKPE. 2003. Atlas des poisons et crustacés du Bénin. Eaux douces et saumâtres. Afrique gestion. Cotonou, Benin.

PAETH, H., BORN, K., PODZUN, R. & JACOB, D. 2005. Regional dynamical downscaling over West Africa: model evaluation and comparison of wet and dry years. *Meteorologische Zeitschrift* 14: 349-367.

PAINE, R. T. 1969. A note on trophic complexity and community stability. *Am. Nat.* 103:91-93.

PAUGY, D., LEVEQUE, C. & TEUGELS G. G. (eds.). 2003a. Faune des poissons d'eaux douces et saumâtres de l'Afrique de l'Ouest. Tome 1. Collection Faune et Flore tropicales 40. IRD, Paris.

PAUGY, D., LEVEQUE, C. & TEUGELS G. G. (eds.). 2003b. Faune des poissons d'eaux douces et saumâtres de l'Afrique de l'Ouest. Tome 1. Collection Faune et Flore tropicales 40. IRD, Paris.

PETR, T. 2000. Interactions between fish and aquatic macrophytes in inland waters. A review. Fisheries Technical Paper No. 396. FAO, Rome. p. 185.

PRODECOM 2006. Schéma directeur d'aménagement de la commune de Malanville: analyse et diagnostic. SERHAUS-SA, Cotonou-Bénin. p. 23.

RAMSAR 2010. http://ramsar.wetlands.org/Portals/15/BENIN..pdf. Accessed December 2010

SAGUA, N.O. 1978. The effect of Kainji Dam, Nigeria on the fish production in the River Niger below the dam at Faku. CIFA Technical Paper No. 5: 209-294p.

SOIL SURVEY STAFF 1975. Soil taxonomy. A basis system of soil classification for making and interpreting soil surveys. Agriculture Handbook 436. Soil Conservation Service, U.S. Department of Agriculture. Washington, D.C., USA.

SOIL SURVEY STAFF 1990. Keys to soil taxonomy, 4th edition. SMMSS Technical Monograph No. 19. Virginia Polytechnic Institute and State University. Blacksburg, Virginia, USA.

SWANN, L. 2007. A fish farmer's guide to understanding water quality. Aquaculture extension Fact sheet AS-503. India Sea Grant Program. http://www.ansc.purdue.edu/aquanic.

THE WORLD GAZETTEER 2010. http://www.world-gazetteer.com/wg.php?x=&men=gpro&lng=en&dat=32&geo=-35&srt=npan&col=dq&pt=c&va=&geo=366750338. Accessed November 2010.

THOMPSON, J.R. & POLET, G. 2000. Hydrology and land use in a Sahelian floodplain wetland. *Wetlands* (20) 4: 639-659.

TOKO, I. 2007. Amélioration de la production halieutique des trous traditionnels à poissons ('Whedos') du delta de l'Ouémé (sud Bénin) par la promotion de l'élevage des poissons-chats *Clarias gariepinus* et *Heterobranchus longifilis.* Dissertation aux facultés des sciences, département de biologie; Facultés Universitaires Notre-Dame de la Paix. Namur, Belgique.

VAN DEN BOSSCHE, J. P. & BERNACSEK G. M. 1990. Source book for the inland fishery resources of Africa; CIFA Technical Paper Vol. 2, 18/2. FAO, Rome.

WELCOMME, R.L. 1975. The fishery ecology of African floodplains. CIFA Technical Paper 3. FAO, Rome.

WELCOMME, R.L. 1979. Fisheries ecology of Floodplain Rivers. London, Longman. p 317.

WELCOMME, R.L. 1985. River fisheries. Fisheries Technical Paper 262, FAO, Rome.

WELCOMME, R.L. & DE MERONA, B. 1988. Fish communities of rivers – Peuplements ichtyologiques des rivières. Pp. 251-276 *In* C. LEVEQUE, M. BRUTON & G. SSENTONGO (eds.). Biologie et écologie des poisons d'eau douce africains. ORSTOM 216. Paris, France:

WELCOMME, R.L. 2003. River fisheries in Africa: their relationship to flow regimes. NAGA, WorldFish Center Quarterly 26 (3): 22-26.

WILLAIME, P. & VOLKOFF, B. 1963. Soil Maps of Africa. ORSTOM, Office de la recherche scientifique et technique outre mer, Paris. Online in the 'cartothèque' of the former ORSTOM and now IRD (Institute de recherche pour le développement): http://www.cartographie.ird.fr/sphaera/images/telechargement/02023.pdf

WINEMILLER, K.O. & JEPSEN, D.B. 1998. Effects of seasonality and fish movement on tropical river food webs. *Journal of Fish Biology* 53 (Supplement A): 267-296.

WHITFIELD, A.K. & BLABER, S.J.M. 1976. The effects of temperature and salinity on Tilapia rendalli, Boulanger 1896. *Journal of Fish Biology* 9: 99-104.

CHAPTER III

CURRENT MANAGEMENT OF THE 'WHEDO'-AQUACULTURE-SYSTEM

1. INTRODUCTION

Malanville (North-East-Benin) is located 1,130 km upstream of the estuary of the River Niger (MORITZ *et al.* 2006). With a length of 4,183 km, the Niger is the largest river in West-Africa. In Benin it covers an area of 274 km^2 at peak flood and forms along 140 km the north-eastern frontier (WELCOMME 1985). The Sota is a tributary with a length of 250 km flowing into the Niger at Malanville (VAN DEN BOSSCHE & BERNACSEK 1990). Almost two million people live in the Niger Basin in Benin (ANDERSEN *et al.* 2005) and these rivers play an important role in the life of this large and densely populated region by directly contributing to agriculture, fisheries, hunting, grazing and water resources.

Regional fishing is an important traditional activity (PRODECOM 2006); however, local fishermen, fishmongers and consumers complain about the decline of local fish diversity, its quantity and its diminishing size. Reasons for this phenomenon are inter alia an increasing fishery pressure in concert with the utilization of disastrous fishing methods, caused by the increasing demand of a steeply growing population as well as the destruction of spawning areas as a consequence of lacking integrated approaches to floodplain management.

Consequently, fishermen but also farmers suffering from increasing crop failures as effect of the climate change are forced to diversify their sources of income. Therefore, they started to cultivate fish in 'Whedos', *i.e.* in ponds dug in the floodplain of the main rivers. Some feeding and management occur and high yields from these 'Whedos' have been reported (WELCOMME 1975a). Although, this is a traditional practice of fish rearing in the Ouémé River Valley in southern Benin, it was not known in Malanville before 1998 and the 'Whedos', in the North called 'Tschifi dai' ('fish hole' in the local Dendi language), differ significantly from those in the South of Benin (see LALÈYÈ *et al.* 2007) especially with regard to their history of development, management strategies, dimensions, climatic conditions, physico-chemical water parameters and fish species diversity.

Since their introduction in 1998 growing fish in 'Tschifi dais' has become an important activity. In 2007, we identified 464 'Tschifi dais' covering a surface area of approximately 9.3 hectare. Nowadays, the system is well integrated into the lives of many farmers and their families and plays an important role in supplementing earnings and protein supply especially for the extremely poor.

In view of their positive role in increasing fish production, and the enhancement of livelihoods, a better knowledge of the present state of 'Whedo' management is necessary.

2. MATERIALS AND METHODS

This analysis is based on personal observation, participation in management and interviews with fish farmers, fishmongers and consumers over the period 2007 to 2009. We visited 12 villages in four districts of northern Benin (Garou, Toumboutou, Madekali and Malanville) known to practice the 'Tschifi dai'-system and collected information from 49 fish farming groups (all of the 'Tschifi dais' we studied were managed by some kind of collective either community or family based).

In all 'Tschifi dais', fish were sampled using a small seine (2m x 1m, mesh size 5mm). At final harvest, fish were caught with a big seine (20m x 1m, mesh size 5mm), sorted, counted and weighted according to species and total productivity was recorded. Fish were identified according to PAUGY *et al.* (2003a, b), LÉVÊQUE *et al.* (1990, 1992), TREWAVAS (1983) and MORITZ *et al.* (2006). The positions of the 'Tschifi dais' shown were recorded with the global position system Garmin Etrex Legend.

3. GENERAL KNOWLEDGE OF THE 'TSCHIFI DAIS'

3.1 HISTORY AND DEVELOPMENT

The 'Whedo' system, locally named 'Tschifi dai'-system, was introduced to the community of Malanville by the CeCCPA (Centre Communale pour le Promotion Agricole) in 1998 which furthermore provided technical support and training for several farmers and fishermen. Thus, the system is no traditional activity although fishing in floodplain depressions and marshes is common in the region and some individuals had already started to practice fish faming in small depressions left in the floodplain after the excavation of clay for brick construction in 1989.

3.2 Social Structure

Generally, fish farmers can be considered as agro-fishermen; 91 percent stated that their major income comes from agriculture with fishing as a sideline. Only 4.5 percent characterize themselves as fulltime fishermen. Nowadays, fishing as main profession is hardly sufficient to support livelihoods. Indicated reasons are the plummeting fish catch, the reduced size of the fish and the increase in labour to catch one unit of fish. Consequently, people are forced to diversify their sources of income, thus becoming agro-fishermen, animal breeders, providers of services, etc.

People usually unite to form associations of 22 members on average (min. 3; max. 80 members) possessing an average of three 'Tschifi dais' (min. 1; max. 8). Fish farming seems to be a man's business and generally women are not integrated in the fishing activity but we met one association consisting exclusively of women. Nearly all (90 %) of the groups are hierarchically organized possessing a president, a secretary and a treasurer; each of them responsible for specific tasks. Other positions are organizer, guard and salesman.

Regarding the land use rights, 78 % of the groups are led by landowners who inherited their land as previously noted by Dossou (2008). Most of the rest of the land used for 'Tschifi dais' is on loan from the community, meaning from the village chief. A big part of the land used for 'Whedo' construction, mainly marshy lowland, is not suitable for cultivation because of intense flooding during a long period of the year. In return for the access to the land, the fish farmers acknowledge the chief with gifts in the form of fish.

3.3 Structural Diversity

'Tschifi dais' (TD) can be distinguished according to their location and hydrology:

- Category 1: TD flooded directly by the overspill of rivers;
- Category 2: TD flooded indirectly through overflowing irrigation channels and rice fields;
- Category 3: TD only filled by ground water and local rain.

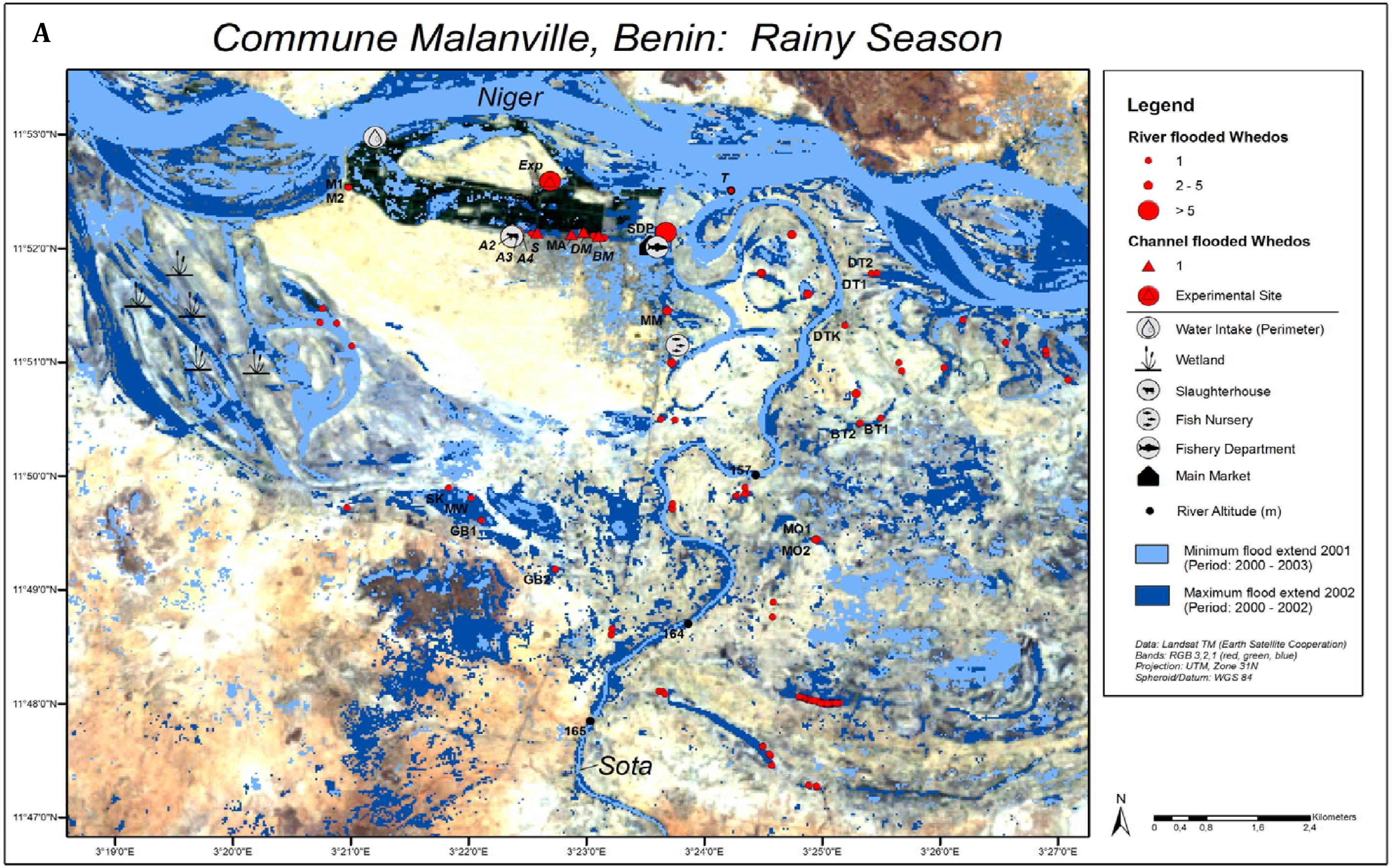
Figure 1 shows the different 'Whedos' and their locations within the floodplain of the River Niger and Sota. The figure also shows minimum and maximum floods during the rainy season between 2000 and 2003 and thus also indicating the 'Whedos' of the category 3 which are only inundated during extreme flood events.

The TDs have a median size of 200 m^2 (mode: 200m^2, n = 74, min. 35.6 m^2; max. 7170 m^2) with varying depth according to the season. During the rainy season in 2008 the water level averaged 92 cm, and dropped to 52 cm during the dry season, excepting those that dried out completely. Secchi Disk visibility varies from a mean of 12.8 cm during the dry season to 29.5 cm during the rainy season. Most 'Tschifi dai' are covered with a dense mat of vegetation mainly consisting of free floating plants such as *Pistia stratiotes* and *Eichhornia crassipes,* but also *Neptunia oleracea, Ludwigia* spp. and *Poacea*-species such as *Echinochloa colona* and *Paspalum scrobiculatum.*

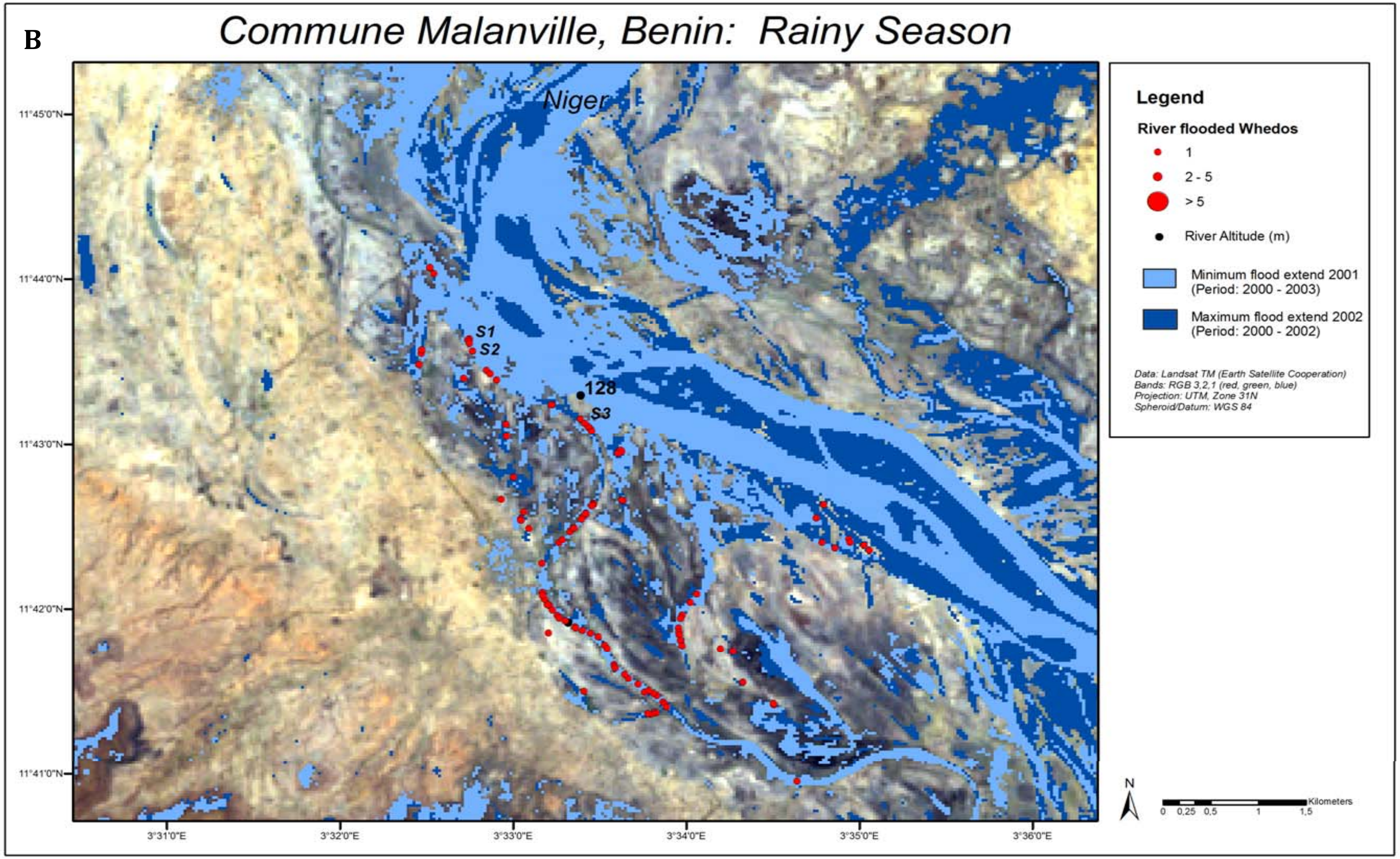
4. MANAGEMENT STRATEGIES

4.1 MAINTENANCE

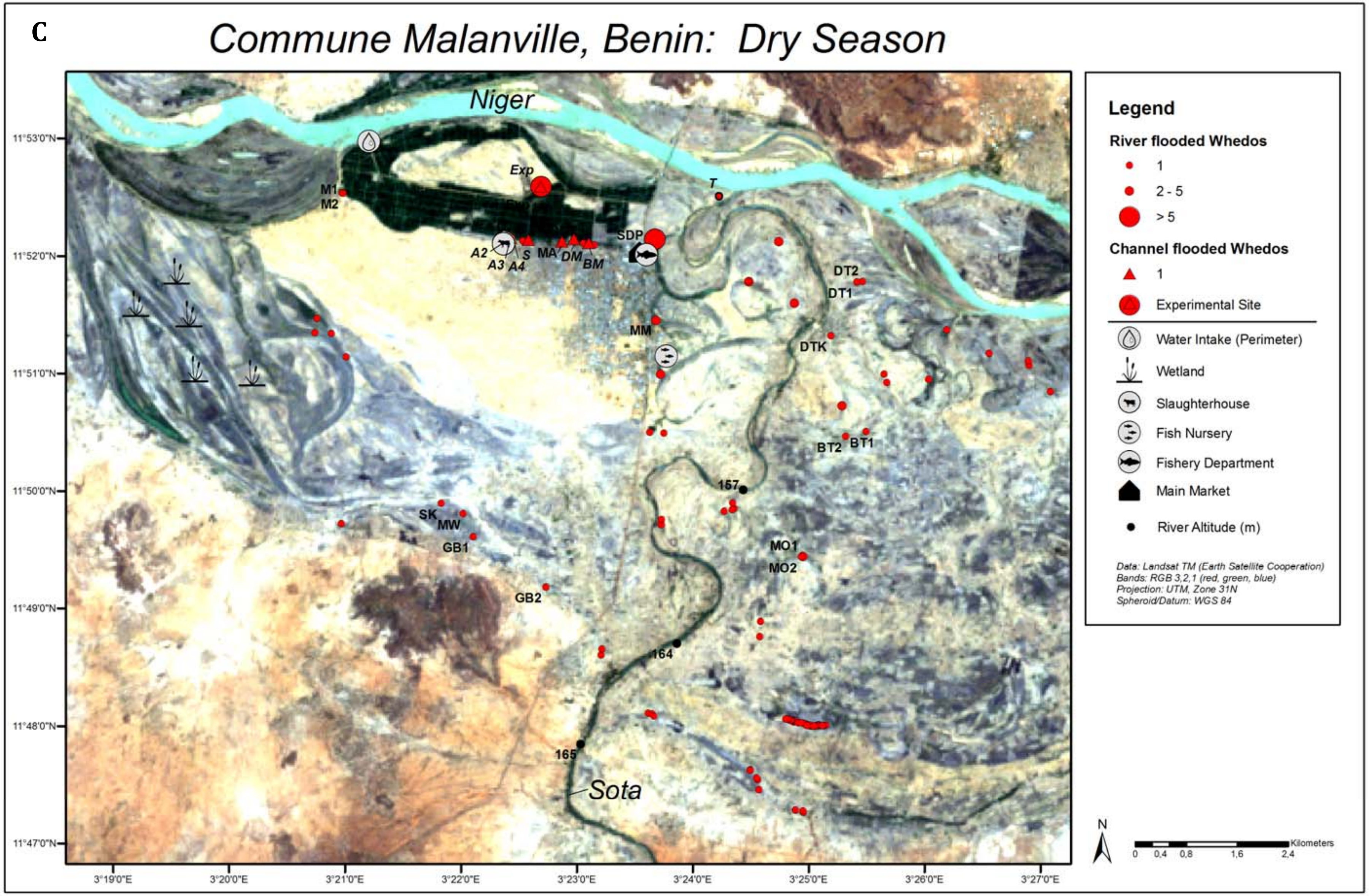
Farmers largely neglect their 'Tschifi dais' and maintenance mainly refers to the removal of macrophytes at the end of the season to facilitate fish capture. At final harvest, some groups take advantage of the low water level and remove the bottom mud to reinforce the banks. In contrast to the practice in the Ouémé Delta, gardening or cultivation on the banks is not practiced since fish holes are usually too far away from the homestead and thus difficult to keep under surveillance. Theft is especially a problem in the villages where some 'Tschifi dais' were cleaned out completely. Consequently, some groups place branches of trees in the pond to prevent the use of fishing nets. Additionally, the branches also impede animals, especially cattle, to enter the pond.



A
Commune Malanville, Benin: Rainy Season
Niger
Sota
Exp
M1
M2
T
SDP
A2
A3
A4
S
MA
DM
BM
DT2
DT1
MM
DTK
BT2
BT1
157
SK
MW
GB1
GB2
MO1
MO2
164
165
11°53'0"N
11°52'0"N
11°51'0"N
11°50'0"N
11°49'0"N
11°48'0"N
11°47'0"N
3°19'0"E
3°20'0"E
3°21'0"E
3°22'0"E
3°23'0"E
3°24'0"E
3°25'0"E
3°26'0"E
3°27'0"E
Legend
River flooded Whedos
1
2 - 5
> 5
Channel flooded Whedos
1
Experimental Site
Water Intake (Perimeter)
Wetland
Slaughterhouse
Fish Nursery
Fishery Department
Main Market
River Altitude (m)
Minimum flood extend 2001 (Period: 2000 - 2003)
Maximum flood extend 2002 (Period: 2000 - 2002)
Data: Landsat TM (Earth Satellite Cooperation)
Bands: RGB 3,2,1 (red, green, blue)
Projection: UTM, Zone 31N
Spheroid/Datum: WGS 84
N
Kilometers
0 0,4 0,8 1,6 2,4


B
Commune Malanville, Benin: Rainy Season
Niger
S1
S2
S3
128
11°45'0"N
11°44'0"N
11°43'0"N
11°42'0"N
11°41'0"N
3°31'0"E
3°32'0"E
3°33'0"E
3°34'0"E
3°35'0"E
3°36'0"E
Legend
River flooded Whedos
1
2 - 5
> 5
River Altitude (m)
Minimum flood extend 2001 (Period: 2000 - 2003)
Maximum flood extend 2002 (Period: 2000 - 2002)
Data: Landsat TM (Earth Satellite Cooperation)
Bands: RGB 3,2,1 (red, green, blue)
Projection: UTM, Zone 31N
Spheroid/Datum: WGS 84
N
0 0,25 0,5 1 1,5
Kilometers

C



Commune Malanville, Benin: Dry Season
Niger
Sota
Exp
M1
M2
T
SDP
A2
A3
A4
S
MA
DM
BM
DT2
DT1
MM
DTK
BT2
BT1
157
SK
MW
GB1
GB2
MO1
MO2
164
165
11°53'0"N
11°52'0"N
11°51'0"N
11°50'0"N
11°49'0"N
11°48'0"N
11°47'0"N
3°19'0"E
3°20'0"E
3°21'0"E
3°22'0"E
3°23'0"E
3°24'0"E
3°25'0"E
3°26'0"E
3°27'0"E
Legend
River flooded Whedos
1
2 - 5
> 5
Channel flooded Whedos
1
Experimental Site
Water Intake (Perimeter)
Wetland
Slaughterhouse
Fish Nursery
Fishery Department
Main Market
River Altitude (m)
Data: Landsat TM (Earth Satellite Cooperation)
Bands: RGB 3,2,1 (red, green, blue)
Projection: UTM, Zone 31N
Spheroid/Datum: WGS 84
N
0 0,4 0,8 1,6 2,4
Kilometers

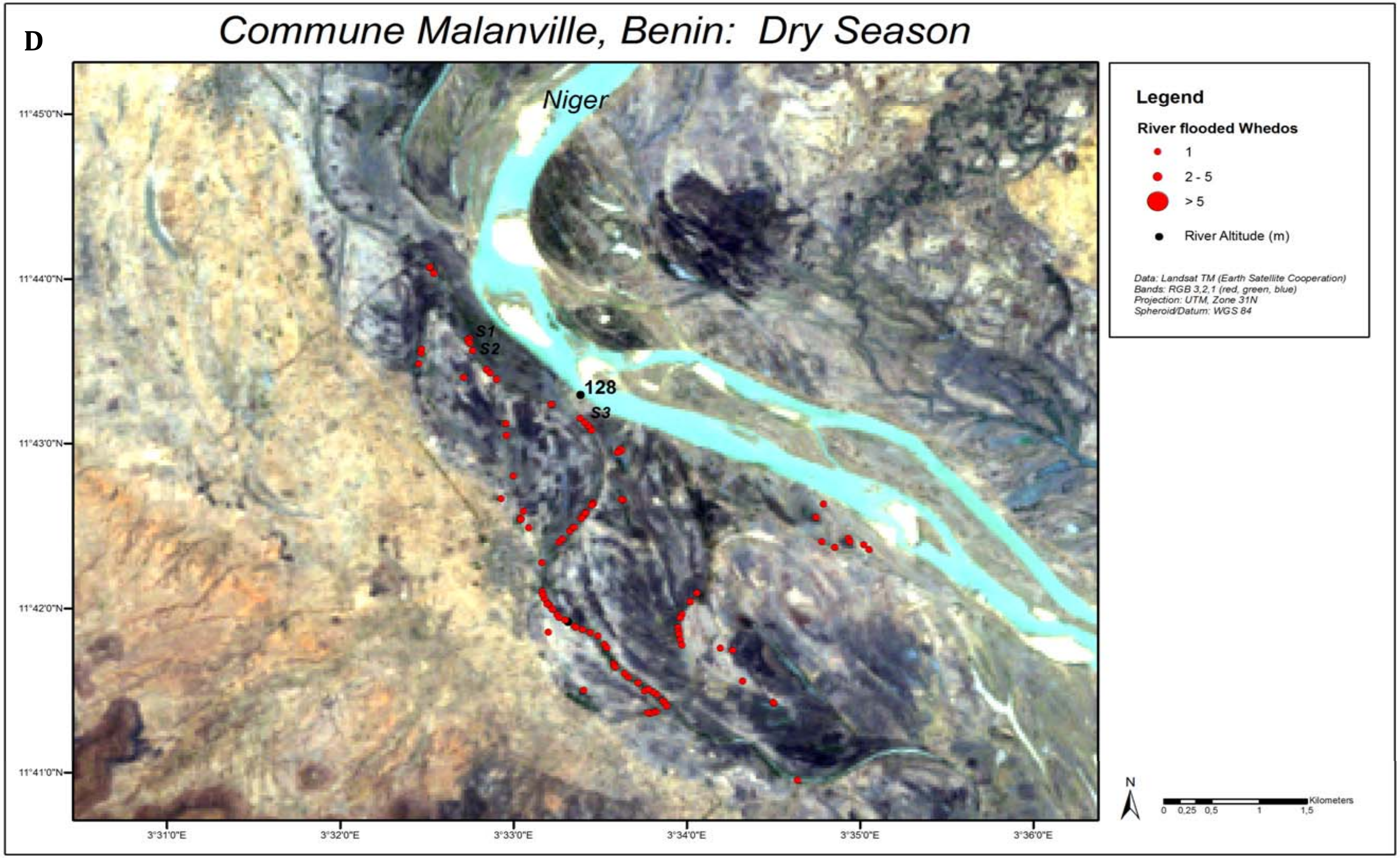

D
Commune Malanville, Benin: Dry Season
Niger
S1
S2
128
S3
Legend
River flooded Whedos
1
2 - 5
> 5
River Altitude (m)
Data: Landsat TM (Earth Satellite Cooperation)
Bands: RGB 3,2,1 (red, green, blue)
Projection: UTM, Zone 31N
Spheroid/Datum: WGS 84
11°45'0"N
11°44'0"N
11°43'0"N
11°42'0"N
11°41'0"N
3°31'0"E
3°32'0"E
3°33'0"E
3°34'0"E
3°35'0"E
3°36'0"E
N
0 0,25 0,5 1 1,5
Kilometers

Fig. 1: GIS Map of Malanville and the surrounding area with the studied 'Tschifi dais' located in the floodplain of the River Niger and Sota.
The figure A shows the city Malanville and its environment and B shows the surrounding of Madekali meaning the course of the River Niger easterly of Malanville during the rainy season. The black area along the River Niger represents the area arable for rice cultivation. The bright blue indicates the minimum and the dark blue the maximum intension of the flood between 2000 and 2003. The figures C and D are showing the same areas than A and B, but in the dry season.

4.2 Feeding regime

Approximately 70 percent of the groups have started to supply supplementary feed during the dry season when the TDs are accessible but feeding is infrequent. Although the majority of groups said they fed between once per day and once per week, we could not find any proof of this. It is more common to feed at the beginning of the flood to attract fish or cause them to stay in the TD.

Rice bran is by far the most used supplemental feed since it is free and easily available from the numerous local mills. Bran from millet, maize and sorghum are also used but to a lesser extent because they are also fed to ruminants and have to be purchased on the market if not produced on-farm. A few groups also use kitchen-waste or by-products from the slaughterhouse *e.g.* blood and bone meal. Feed is usually mixed with cold or hot water and offered in the form of palm-sized dough-balls. Some groups add clay to guarantee that the dough-balls sink to the bottom. However, the vast majority of fish growth is due to the natural food supply.

4.3 Stocking regime

The kind of stocking depends primarily on the location of the TD. Category 3 has to be stocked artificially, but nearly 56 percent of the other groups also stated that they stock their ponds in addition to the natural fish supply. Most commonly stocked species are *Clarias* sp., *Tilapia* sp., and *Heterotis niloticus*. The majority purchase their fingerlings from local fishermen, though it is not uncommon for 'Tschifi dai' operators to collect fish themselves, from for example, rice fields. Restocking also takes place after the annual harvest with some groups putting fingerlings back to grow some more. However, this stocking is more or less haphazard, with no consistent strategy or knowledge of appropriate stocking. Basically, farmers just take whatever they can get at any time they can get it. Our observation showed that artificial stocking of other species than *Clarias* did not significantly affect the overall biomass at final harvest. Nine 'Tschifi dai' were additionally stocked with *Tilapia* spp. (mostly *O. niloticus* and *S. galilaeus*) of different size and density without removing *Clarias* with the result that there was little or no survival to harvest. Most of the harvest is thus mainly a consequence of the intensity of natural stocking. Standing stock at harvest was 1.2 kg/m^2 on average.

5. EXPLOITATION

5.1 Period and frequency

The period of exploitation depends on the extent of the annual floods and the location of the 'Tschifi dai' within the floodplain, but the main season is from February to April (Fig. 2) meaning just prior to the onset of the rainy season. In 2007 and 2009 most of the TD were harvested between March and April because of the relatively minor flood in the previous years, whereas in 2008 the majority were harvested in May reflecting the high water level due to the strong inundation in 2007. Although season and water level are the key indicators of harvest time, farmers also consider the market price of fish. In general, fish prices increase significantly at the end of the dry season because of low landings from the river fishery. Farmers consequently attempt to wait as long as possible into the dry season to maximize the value of their harvest on the local market.
The majority of the TDs (74 %) are harvested in one day by dragging a seine net several times the length of the pond. Bigger or highly productive 'Tschifi dais' may be harvested several times at weekly intervals.

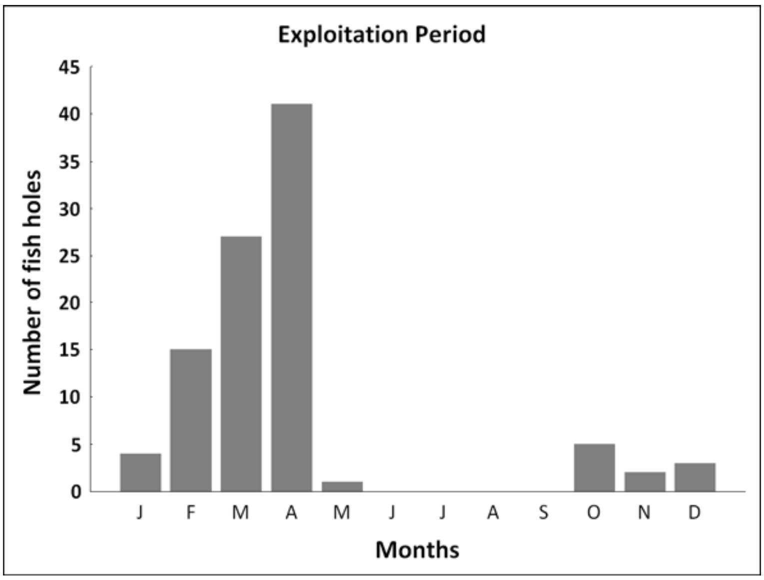


Fig. 2: Exploitation time of the studied 'Tschifi dais' from 2007 to 2009 (n = 111).

5.2 Gears and fishing methods

At harvest, 75 percent of the groups interviewed use one or several motor pumps to reduce the water level of the TD. The majority of the farmer posses motor pumps for the cultivation of rice and vegetables during the dry season. After lowering the water level, farmers use a big seine (approximately 20m long and 1m deep, mesh size 5mm). Some groups don't remove the vegetation cover completely but leave some patches of floating macrophytes to serve as shelter for the fish and thus preventing them from hiding in the mud. When netting is completed, some groups continue to search for fish hidden in the mud. For this purpose they use harpoons, wooden baskets, sieves or simply their hands. Children are also involved in the harvest stealing small and economically unimportant fish and hiding them in their pockets. Though the owners are aware of this, it is generally considered as compensation for their work. Some groups hire labour for the harvest which is usually paid with fish.

Harvested fish are either kept in large metal bowls sometimes filled with water, woody baskets or in small water holding depressions dug next to the pond. The respective method depends on the locality; in the city bowls are the most common whereas in the villages farmers usually dig small pools. The main reason why farmers keep the fish in water is to prevent a lost of body weight and value.

6. CATCH AND DISPOSITION OF HARVESTED FISH

6.1 Diversity of fish

Prior to the flood the species diversity of the TD is highly reduced compared to the fish species recorded after the flood (Hauber *et al.* 2011). With regard to two selected TD, we observed a species reduction of 64 % and 75 %, respectively by comparing the species richness shortly after inundation with those at the end of the dry season. Table 1 lists the species captured at the end of the dry season with their local *Dendi* names. The majority of the TD showed low oxygen levels (often 2 mg/l or less) and very high salt concentrations (>4000 µS/cm), which, in addition to high evaporation rates during the dry season, were consequences of the large amounts of decaying organic matter from autochthonous and allochthonous sources. As a result of pollution from human settlements, total anoxia not uncommonly causes catastrophic die-offs. All species detected at the end of the dry season are known for their ability to survive low oxygen levels.

Tab. 1: Fish species detected at the end of the dry season and their local names.

Species	**Local name (*Dendi*)**
Protopteridae	
Protopterus annectens	Siyibi
Polypteridae	
Polypterus senegalus	Gondo-Kououga
Osteoglossidae	
Heterotis niloticus	Koualah
Mormyridae	
Brevimyrus niger	Wassi
Claroteidae	
Auchenoglanis occidentalis	Koutoukou tchiré, Bouro
Clariidae	
Clarias gariepinus	Dessebi, Dessi
Heterobranchus longifilis	Dessi tchiré
Cyprinodontidae	
Epiplatys spilargyreius	-
Nothobranchius kiyawensis	-
Channidae	
Parachanna obscura	Corombou
Cichlidae	
Hemichromis cf. *letourneauxi*	Koula-Koula
Oreochromis niloticus	Fotoforoh-Bi, Kossia-Bi
Sarotherodon galilaeus	Kossia-Koare
Anabantidae	
Ctenopoma sp.	-
Mochokidae	
Synodontis schall	Djidjiri, Koutoukou
TOTAL	**15**

6.2 Total and Species-Specific Annual Biomass Harvested

Changes in species composition and richness in TD post-flood compared to their status at the end of the dry season is most obvious at final harvest. Conspicuous is the dominance of only one genus (*Clarias* spp.) in almost all investigated 'Tschifi dais' by the end of the dry season. In the 22 harvests in which we participated from 2008 to 2009, *Clarias* accounted 81.4% on average of the total biomass, whereas in more than 50 % of the TDs *Clarias* formed 95% of the total biomass.

Table 2 gives an overview of the different species caught and their percentage of the total biomass at final harvest. An average of 92.4 percent of the total biomass of *Clarias* caught is smaller in size than 350 grams, whereas only 7.6 percent of the harvest consists of fish with an average weight of 900 grams. The majority (72 %) consists of

Clarias with an average weight of only 40 grams.

Tab. 2: Fish species recorded at final exploitation and their percentage on the total biomass harvested.

Species / 'Whedo'	*Clarias* sp.	*Heterotis niloticus*	*Tilapia* spp.	*Polypterus senegalus*	*Protopterus annectens*	*Heterobranchus longifilis*	others*
2008							
DamatabiNsidou	99,6	0,0	0,0	0,4	0,0	0,0	0,0
Noma Idé I	100,0	0,0	0,0	0,0	0,0	0,0	0,0
Noma Idé II	97,4	0,0	1,7	0,0	0,0	0,0	0,9
Gounai Windi	93,9	6,1	0,0	0,0	0,0	0,0	0,0
Lakalikanei I	92,0	0,0	6,7	0,0	0,0	1,4	0,0
Lakalikanei II	66,3	0,0	12,6	0,0	0,0	0,0	21,2
Dagara Mama	87,5	11,8	0,7	0,0	0,0	0,0	0,0
Macheresse	38,6	27,1	29,8	1,4	3,1	0,0	0,0
2009							
Botcho Manou	99,0	0,0	0,4	0,6	0,0	0,0	0,0
DamatabiNsidou	90,8	7,6	0,0	0,6	0,1	0,0	0,9
Noma Idé Village	12,8	24,1	0,0	0,0	0,0	63,1	0,0
Noma Idé I	100,0	0,0	0,0	0,0	0,0	0,0	0,0
Noma Idé II	99,6	0,0	0,0	0,3	0,0	0,0	0,1
Goro Bani I	89,6	0,0	9,0	1,4	0,0	0,0	0,0
Macheresse	24,8	18,0	56,8	0,0	0,4	0,0	0,0
Mamamassou	86,5	0,0	13,5	0,0	0,0	0,0	0,0
Mourou Windi	98,9	0,0	1,1	0,0	0,0	0,0	0,0
Heoufounin 3	100,0	0,0	0,0	0,0	0,0	0,0	0,0
Heoufounin 4	96,4	0,0	1,3	0,0	2,3	0,0	0,0
Heoufounin 5	96,6	0,0	0,0	0,0	3,4	0,0	0,0
Heoufounin 6	95,8	0,0	4,2	0,0	0,0	0,0	0,0
Heoufounin 7	25,6	0,0	61,7	0,0	9,7	0,0	3,1

others* = *Brevimyrus niger, Ctenopoma* sp., *Auchenoglanis occidentalis*, etc.

By converting the biomass harvested on a hectare basis separated for each of the TD, the annual biomass averaged 11.8 tons/ha in 2008 and 2009 (see Tab. 3).

However, as previously mentioned, biomass is highly dependent on the flood regime of the previous year (WELCOMME & DE MÉRONA 1988), thus the influence of the extensive flooding in 2007 can be seen in the average yields of 17 tons/ha in 2008 and 8.6 tons/ha in 2009, following a relatively dry 2008. In years of weak flooding, the biomass yield of the TD consists mostly of fish left from the previous year.

When summarizing the total biomass harvested on the total water surface of the exploited TD, annual average yield was 3 t/ha in 2008 to 2.1 t/ha in 2009. Unfortunately, there are no data available on the biomass production of the TD in the North but yields of the 'Whedos' in the Ouémé-Delta ranged from 2.06 tons/ha in 1955 to 1.31 tons/ha in 2001 (LALÈYÈ *et al.* 2007; WELCOMME 1971), although it is not clear if the author refers to single TD or to the total water surface area.

According to case studies of the 'Ebe'-fishery in Ghana, similar 'Whedos'/fish holes yield between 13.3 and 26.7 t/ha water surface annually (GTZ 2002).
Although this sounds inconceivable, it should be borne in mind that with the retreat of the flood a large percentage of fish dwelling in the floodplain get trapped within these depressions. LOWE-MCCONNELL (1964) found 870 fish belonging to 36 species in a floodplain pool of only 19 m³. The fact that the density of 'Whedos' installed in the Ouémé Delta is far higher than in the North might explain their lower annual yields.

However, the high differences of output within the TD in the North are probably a result of their location within the floodplain, the feeding regime and the number of TD in their close environment since our data does not proof any relation between the biomass harvested to the dimension or the age of the TD.

Tab. 3: Biomass output of the different 'Whedos' from 2008 to 2009.

Group	Total weight (kg)	surface area (m^2)	Output (kg/ha)
2008			
Lakalikanei I	562,9	271,8	20712,1
Lakalikanei II	8,8	36,6	2390,7
Macheresse	513,6	7170,0	716,2
Dagara Mama	6,8	142,7	476,6
Eloa Madekali	235,8	114,0	20684,2
Gounai Windi	164,0	108,0	15185,2
Bobosotjiré	455,0	163,4	27845,8
DamatabiNsidou	449,3	61,0	73655,7
Noma Idé 1	88,5	207,0	4275,4
Noma Idé 2	84,7	239,7	3533,6
2009			
Heoufounin 3	3,3	96,2	337,8
Heoufounin 4	79,2	247,0	3207,5
Heoufounin 5	37,1	46,5	7978,5
Heoufounin 6	77,2	314,3	2455,8
Heoufounin 7	11,4	35,6	3184,6
Lakalikanei I	218,0	271,8	8022,1
MamaMassou	137,1	60,7	22570,8
Macheresse	413,1	7170,0	576,1
Botchou Manu	39,0	702,0	555,6
Bobosotjiré	46,0	200,0	2300,0
DamatabiNsidou	172,0	61,0	28188,5
Noma Idé Kotchi	71,5	275,5	2595,3
Noma Idé 1	108,0	418,5	2580,6
Noma Idé 2	99,4	480,0	2069,8
Goro Bani	486,9	170,0	28641,2
Mourou Windi	359,1	160,0	22445,0
Min. biomass output (kg/ha)			**337,8**
Max. biomass output (kg/ha)			**73655,7**
Average biomass (kg/ha)			**11814,8**

7. THE VALUE CHAIN

While fish farming is almost exclusively a males' business, women are integrated within this sector in marketing, processing and distribution of the fish. The majority of the fishmongers (79 %) are relatives of the fish farmers and are directly involved in determination of the harvest date. Since women are usually united in professional associations they also get informed by their association president. Mongers arrive at the site and purchase the fish directly after the harvest. Usually demand is greater than the harvested supply and the waiting fishmongers will evenly share the available fish. The fish are sold in locally accepted scale units consisting of two different sizes of metal basins, the smaller and more common one, holding an average of 21 kg, is known as 'Weguisé'. The price of one basin varies according to the size of the fish. Small fish (average weight 40 g) cost 431 FCFA (0.66 €) per kg while medium sized fish (average 350 g) sell for 536 FCFA (0.82 €) per kg. Basins filled with different size classes of fish generate about 513 FCFA (0.78 €) per kg. Bigger fish are mostly sold individually. In comparison, market prices of fish from the river fishery are generally higher, with one kilogram of fresh *Clarias* selling for 879 FCFA (1.34 €).

After purchasing the fresh fish, mostly *Clarias*, the mongers usually process the fish before reselling, though some are transported alive in water for sale at their homestead. Processing depends on the species; *e.g. Tilapia* spp. is usually fried whereas the majority of *Clarias* sp. is smoked coiled up and gored on a wooden stick. Smoked fish is not only sold on the local markets but also sold on other major markets *e.g.* in Kandi and exported to Nigeria. One kilogram of smoked Clarias is sold for 2,200 FCFA (3.35 €) on average, while fried Tilapia is offered for 4,245 FCFA (6.48 €). Some women prepare the fish as meals and sell them for consumption on the street.

Consumer preferences differ according to region. The indigenous people around Malanville prefer *Clarias* because it can be easily preserved by smoking. People immigrated from southern Benin prefer *Tilapia* spp. Bigger fish are highly appreciated but most consumers cannot afford the higher prices, so larger specimens are cut up and sold per piece.

8. INCOME

Income from fish farming can be divided into cash and food. According to the farmers, 11 percent sell none of the fish but share them between the group members for home consumption and give some to the village chief as a gift. However, the majority of farmers are cultivating fish to earn some additional income and 65 % of the farmers said they sell more than 80 % of the harvest. Some 62 % of the farmers save a part of the money by depositing it at the CLCAM (Caisse Local de Crédit Agricole Mutuel) or at the treasurer. The rest of the money is divided between the members of the 'Whedo' association. Farmers confirm that earnings derived from the TDs are of great importance since they fall prior to the onset of the new agricultural season when farmers need the money for purchasing seeds, agricultural tools etc. Weddings, baptisms and other events as well as medical treatments and emergency cases are also paid for with the income of aquaculture activities.

The income depends on the size as well as the stocking density of the respective TD. Realized gross income ranges between 68,758 (104.81 €) and 327,000 FCFA (498.5 €) not counting home consumption and donations. The total surface area of the TDs with available economic data was 18,091 m^2 generating an income of 1,990,482 FCFA (3,034.3 €), leading to 1,099,953 FCFA /ha (1,676.80 €). If we convert the outcome to the total 9.3 ha of surface water area under production, the annual gross income of the commune attains 10,207,562 FCFA (15,560 €). This is similar to the findings of Toko (2007) who reported that fishing in 1,050 'Whedos' can yield more than 25 million FCFA (39,117 €). However, these are only gross incomes since we did not consider any costs for construction or inputs such as feed or fingerlings. Usually construction is done directly by the group members and running costs are rather low since feeding is negligible and usually done with products free of charge.

9. MAJOR CONSTRAINTS

Despite the fast development of the TDs there exist some drawbacks hindering the improvement of the current system. In Madekali, fish farmers are in conflict with local fishermen since their TDs are situated in a small branch of the River Niger and the fishermen accuse them of being somehow responsible for reduced fish landings. In Malanville, three fish farmer associations are in conflict with the neighbouring school that raised a claim on the land although the farmers possess deeds of ownership.

However, the most important drawback is theft. These detrimental impacts discourage the owners and deter them from maintaining and feeding their TDs. It is also important to mention that there are also internal problems within groups and a number of associations have already disbanded because of the misbehaviour of the some members affecting the whole alliance.

10. CONCLUSIONS

Because of rapid demographic growth and the overexploitation of the rivers, it is important to look for alternatives to increase fish supply in a sustainable way. In Malanville, the consumption of chilled fish increased from 16,630 kg in 1999 to 33,000 kg in 2007 (unpublished data of the local fishery department). Fish farming in TDs is an attractive system for the rural population because of existing knowledge of post-flood wetland fisheries and because natural stocking also reduces the cost of purchasing fingerlings and solves other procurement problems.

However, the system is still in its infancy. The fact that 72% of the total catch consists of *Clarias* with an average weight of 40 grams, highlights the need to increase the knowledge among the farmers that supplementary feed will enhance their yields.

Farmers should also concentrate their efforts on improving water quality *e.g.* by avoiding sites that are highly polluted. Moreover, it is essential to increase farmers' knowledge on appropriate stocking such as species, size, density and ratio of fish to be stocked and other methods to reduce wasted capital and manpower.

If only 1% of Africa's 12 million hectares of floodplains would be developed as 'Whedos' with an output of 1 t/ha/y, the potential yield would be as much as 120,000 tons per year (BALARIN 1988). But despite this high potential, further studies are needed to clarify whether increasing 'Whedo' construction might transform the nature of the floodplain in a way which will negatively affect its fish community and biodiversity.

According to WELCOMME (1975b), there is no risk of overfishing since the provision of 'Whedos' retains fish that would otherwise escape to the river where there would be inadequate living space for them or that would die through eventual desiccation of the pools and as well from facilitated predation through predators such as birds and piscivorous fish due to the very restricted escape possibilities. Surely, the provision of TDs will increase the area of the plain that holds water during the dry season, thus extending the habitat for air breathing and floodplain dwelling species. Consequently, production from the floodplain could be improved. However, to prevent recruitment overfishing it should be secured that the 'Whedos' are not desiccating and that farmers use nets with an appropriate mesh size (> 20 mm) to guarantee the escape of fingerlings.

It is also not clear if deep ponds might affect riverine species *e.g.* by causing them to stay longer on the floodplain resulting in their premature death because of decreasing water quality. But a high density of the TDs might also have an indirect impact by creating a deranged balance of the species assemblage as a result of an increased appearance of adapted species. Therefore, a drastic extension of the surface area of the 'Whedos' should be avoided; or at least the installation of protected spawning areas should be guaranteed.

11. REFERENCES

ANDERSEN, I., DIONE, O., JAROSEWICH-HOLDER, M. & OLIVRY, J.-C. 2006. The Niger River basin: A vision for sustainable management. K. G. GOLITZEN (ed.). The World Bank. Washington, DC. p. 144.

BALARIN, J.D. 1988. Aquaculture developing planning: The logistics of fish farm project appraisal. Pp 92-106 *In* King, H.R. & Ibrahim K.H. (eds.). Village level aquaculture development. Proc. of Commonwealth consultative workshop, Commonwealth Secretariat Publication, Freetown, Sierra Leone.

DOSSOU, S. 2008. Etudes des potentialités et des contraintes de développement de la pisciculture dans la commune de Malanville au Bénin. Thèse de DEA. Faculté des sciences agronomiques, Université d'Abomey-Calavi. Bénin. p. 83.

HAUBER, M., BIERBACH, D. & LINSENMAIR, K. E. 2011. A description of teleost fish diversity in floodplain pools ('Whedos') and the Middle-Niger at Malanville (North-eastern Benin). Journal *of Applied Ichthyology* 27: 1-5.

GTZ 2002. Back to Basics. Traditional Inland Fisheries Management and Enhancement Systems in Sub-Saharan Africa and their Potential for Development. Universum Verlagsanstalt, Wiesbaden, Germany. p. 203.

LALÈYÈ, P., AKÉLÉ, D. & PHILIPPART J.-C. 2007. La pêche traditionnelle dans les plaines inondables du fleuve Ouémé au Bénin. *Cahiers d'Ethologie* 22 (2): 25-38.

LEVEQUE, C., PAUGY, D. & TEUGELS, G.G. 1990. Faune des poissons d'eaux douces et saumâtres de l'Afrique de l'Ouest. Tome 1. Collection Faune et Flore tropicales 28.IRD, Paris.

LEVEQUE, C., PAUGY, D. & TEUGELS, G.G. 1992. Faune des poissons d'eaux douces et saumâtres de l'Afrique de l'Ouest. Tome 2. Collection Faune et Flore tropicales 28, IRD, Paris.

LOWE-MCCONNELL, R.H. 1964. The fishes of the Rupununi savanna district of British Guiana, South America, Part 1. Ecological groupings of fish species and affects of the seasonal cycle on fish. *J. Limn. Soc. (Zool.)* 45: 103-144.

MORITZ, T., LALÈYÈ, P., KOBA, G. & LINSENMAIR, K.E. 2006. An annotated list of fish from the River Niger at Malanville, Benin, with notes on the local fisheries. *Verhandlung der Gesellschaft für Ichthyologie 5*: 95-110.

PAUGY, D., LÉVÊQUE, C. & TEUGELS, G.G. (eds). 2003a. Faune des poissons d'eaux douces et saumâtres de l'Afrique de l'Ouest. Tome 1. Collection Faune et Flore tropicales 40. IRD, Paris.

PAUGY, D., LEVEQUE, C. & TEUGELS, G.G. (eds). 2003b. Faune des poissons d'eaux douces et saumâtres de l'Afrique de l'Ouest. Tome 1. Collection Faune et Flore tropicales 40. IRD, Paris.

PRODECOM 2006. Schéma directeur d'aménagement de la commune de Malanville: analyse et diagnostic. SERHAUS-SA, Cotonou-Bénin. p. 23.

TREWAVAS, E. 1983. Tilapiine fishes of the genera *Sarotherodon*, *Oreochromis* and *Danakilia*. British Museum (Natural History), London.

TOKO, I. 2007. Amélioration de la production halieutique des trous traditionnels à poissons ('Whedos') du delta de l'Ouémé (sud Bénin) par la promotion de l'élevage des poisson-chats *Clarias gariepinus* et *Heterobranchus longifilis.* Dissertation aux facultés des sciences, département de biologie; Facultés Universitaires Notre-Dame de la Paix, Namur, Belgique. P. 186.

VAN DEN BOSSCHE, J. P. & BERNACSEK, G.M. 1990. Source book for the inland fishery resources of Africa. CIFA Technical Paper Vol. 2 (18/2). FAO, Rome.

WELCOMME, R.L. 1971. Evaluation de la pêche intérieure au Dahomey, son état actuel et ses possibilités. AT 2938. FAO, Rome, p. 95.

WELCOMME, R.L. 1975a. The fishery ecology of African floodplains. CIFA Technical Paper 3. FAO, Rome.

WELCOMME, R.L. 1975b. Extensive Aquaculture Practices on African Floodplains. CIFA Technical Paper 4; Supplement 1 to the Report of the Symposium on Aquaculture in Africa, Accra, Ghana, 30 September – 2 October 1975. p. 791.

WELCOMME, R. L. 1985. Fisheries Technical Paper 262, River fisheries. FAO, Rome

WELCOMME, R.L. & DE MERONA, B. 1988. Fish communities of rivers – Peuplements ichtyologiques des rivières. Pp. 251-276 *In* C. LEVEQUE, M. BRUTON & G. SSENTONGO (eds.). Biologie et écologie des poisons d'eau douce africains. ORSTOM 216. Paris, France:

CHAPTER IV

IMPROVING THE PRODUCTIVITY OF THE 'WHEDO'-AQUACULTURE-SYSTEM

1. INTRODUCTION

Chapter 2 and 3 provide the knowledge essential to determine potential measures for the enhancement of the productivity of the 'Whedo'-aquaculture-system. Chapter 2 presents the results obtained with regard to the ecology of the 'Whedos' and the physico-chemical parameters that play an important role for aquaculture activities, while chapter 3 concentrates on the description of the current management system as well as the biomass production of the 'Whedos' and its species composition.

With the help of these study results, especially in view of the high stocking density of several 'Whedos' combined with many small-sized fish at harvest time, I decided that the provision of feed might be the best method to develop the 'Whedo' aquaculture from an extensive to a semi-intensive system therewith enhancing its biomass production.

Hence, chapter 4 provides basic knowledge on the different types of fish feed, the kind of feed appropriate for the 'Whedo'-aquaculture-system and the potentially available feed materials discovered through extensive market analyses in the region of Malanville. Moreover, the chapter gives an overview on the chemical composition of the different materials and presents those materials selected for the formulation of the supplementations.

Additionally, the chapter gives basic information on the species *Clarias gariepinus* that was used for the feeding trials by describing its aquaculture history, its feeding behaviour, nutrient requirements, and a statement as to why I considered this species as particularly appropriate for stocking.

Finally the chapter presents the results obtained in the two different feeding trials that focused on the supplementary feeding of *C. gariepinus* with locally available and cheap agricultural by- and waste-products. Results were presented with respect to the biomass production and the economic output by accounting of the additional cost of the respective supplementary feed.

2. BASIC KNOWLEDGE ON FISH FEED

Generally, in systems with low stocking densities the nutrient requirements of fish can be met by natural food supply and fertilization in order to enhance the natural food web.

But under high stocking densities or if higher yields are to be achieved, it is necessary to add artificial or exogenous feed to the pond, because natural food production, even combined with fertilization, will not be sufficient to support a dense fish population. However, this goal can be achieved on one side by using supplementary feeds such as rice bran, crop wastes and water plants that is mostly done in semi-intensive production systems or on the other side by using complete diets which are suitable for intensive fish farming (GIETEMA 1999).

2.1 TYPES OF FISH FEED

Supplementary feed is commonly applied in semi-intensive aquaculture and is based on the natural food supply, which is still the primary source of nutrients for the fish (DE SILVA 1993). Since natural feed tends to have a well-balanced nutrient content, meaning adequate amounts of energy, protein, vitamins and minerals, supplementary feeds do not have to meet the complete nutrient requirements. With regard to the high protein supply from natural feed, in semi-intensive production systems protein supplementation is likely to be less important than the supplementation of non-protein-energy. Energy for example in form of carbohydrates should be supplied in order to reserve natural protein for growth (HALVER 1989).

But even though the supplementary feeds will not necessarily enhance growth, their application will increase the production of natural food organisms; and thus increase the value of the natural food supply in the culture system (GIETEMA 1999).

In contrast to supplementary feeds, complete diets are formulated in order to satisfy the requirements of fish completely. This is especially necessary for high production levels, high stocking densities, oligotrophic systems and hatcheries because natural food supply will become relatively insignificant, and the requirements of fish have to be almost completely met by the artificial feed. Because of their high and well-balanced nutrient content, complete diets are more expensive than supplementary feeds and are usually processed into pellets, granules and crumbles (JAUNCEY 1998).

However, with regard to the local conditions of the study area, including the lack of traditional aquaculture practices and financial means, the low fish prices on the local market, as well as the competition for high-protein food by the local population, the application of complete diets is usually economically nonviable. Therefore, in the following the focus is aimed on semi-intensive grow-out production levels and thus complete diets are irrelevant and will not be mentioned further.

2.2 Supplementary Feed for Semi-intensive Production

As already mentioned the aim of the study is the development of the 'Whedo' aquaculture from an extensive system to a semi-intensive system and by increasing the productivity through formulating an appropriate supplementary feed.

Supplementary feed complements the natural food and *vice versa,* thus the amount of feed added to the pond must be adjusted to the natural food supply. Usually newly stocked and fertile ponds do not require supplementation. But with increasing stocking density or yield, as well as increasing fish size, natural food supply will decline, especially at the end of the growth cycle and therefore higher levels of supplementation are necessary. This means that with increasing biomass, the quantity and quality of supplementation feed must increase too (Kumar 1992).

Generally, supplementary feeds can be classified according to their energy and protein contents. Carbohydrate-rich feedstuff can be used to supplement and balance the protein content of the natural food supply, but when this is not sufficient protein-rich materials should be added. However, supplementation is not only a direct feedstuff; even though it is not digested by the fish it serves as fertilizer, especially when added to the pond in an unprocessed stage and will therefore enhance the natural productivity (Jauncey 1998).

Concerning the physical form of the supplementary feed, it is necessary to consider the desirable yield and also the time and motivation available on the part of the farmers. In general, supplementary feeds can range from unprocessed by-products to formulated pellet feeds. Low production levels do not require feed processing; feeding materials can simply be offered to the fish in a raw, unprocessed stage or in form of mash and meal. But higher production levels are only achievable by processing the feed stuff to, for example, dough balls or pellets (Jauncey 1998). Such already processed forms have the advantage that through *e.g.* steam processing nutrients such as starch will be utilized more efficiently and that almost no feed will be wasted as a result of fast dissolving or wind-blown (Kumar 1992).

2.3 Potential Material appropriate as Supplementary Feed

First of all it is important to prove whether or not on-farm feed production or the purchase of fish fodder is economically viable, since feed constitutes an important cost factor accounting for an average of 30 to 60 percent of the production costs (Chong 1993).

With regard to the choice of the ingredients, the materials should be cheap and available in the region as well as the whole year round. Furthermore the feedstuff should possess a high digestibility and a well-balanced nutrient composition (Jauncey 1998). If possible the production of supplementary feed on-farm is more desirable because it contributes to overcome the constraints of availability and lack of financial means of small-scale farmers.

Another crucial aspect is the feeding habit of the fish species being cultivated, meaning the range of food items and the feeding behaviour *e.g.* bottom or surface feeder. Within this study the focus is on the bottom feeding species *Clarias gariepinus* that uses a wide range of food and usually switches the food niche according to the available food supply (Mwebaza-Ndawula 1984). The species is known for its omnivorous feeding habit that converts waste products into valuable animal protein (Lauzanne 1988).

In general, the following categories of feed materials are chiefly suitable to use as supplementation and can be offered solely or in mixture:

1. Protein-rich feedstuff:
    a. Plant origin
        - *Legume seeds and leaves,*
        - *Oilcakes/press cakes,*
        - *Aquatic macrophytes etc.*
    b. Animal origin
        - *Fish trash,*
        - *Meat and poultry by-products,*
        - *Tissue meals,*
        - *Slaughterhouse wastes,*
        - *Terrestrial invertebrates e.g. worms, snails, insects*
        - *Aquatic animals e.g. invertebrates, frogs, crustaceans etc.*

2. Carbohydrate-rich feedstuff:
    - *Cereal grain residues and middlings,*
    - *Tuber and root crops,*
    - *Grasses etc.*

(JAUNCEY 1998; HEPHER 1988).

But animal products can be expensive and if high costs constitute a constraint, it is better to use them only sparingly. However, in general it is not possible to formulate a well-balanced fodder for omnivorous species completely without animal products, because usually plant materials are limited in their nutrient composition, their digestibility and palatability. In order to provide a balanced diet even small amounts of animal products can be helpful and will avoid nutrient deficiency as well as improve palatability (JAUNCEY 1998).

Moreover, plant materials as nutrient components of the feed tend to be deficient in their amino acid profile, mainly the essential amino acids lysine and methionine. The protein content varies usually between 8 percent and 30 percent combined with partial high fibre contents.

In addition, their inclusion level can also be limited because of the presence of non-nutritive components and anti-nutritional or toxic factors. According to MAKKAR (1993) antinutrients are defined as substances which by themselves, or through their metabolic products arising in living systems, interfere with food utilisation and negatively affect the health and production of animals. Raw soybean, for example, contains proteins, which form irreversible complexes with trypsin. Cotton, for instance, contains gossypols, which may cause growth depression and tissue damages (STICKNEY *et al.* 1983; JAUNCEY 1998). Groundnut cake contains beside others protease inhibitor, phytic acid and saponins. Protease inhibitors affect the protein utilisation and digestion of the fish, while phytic acid affects the mineral utilisation. Saponins are steroid or triterpenoid glycosides that are highly toxic to fish when added to the water because they cause damage to the respiratory epithelium of the gills by their detergent action. Furthermore negative effects can also be caused by their surface-active components on biological membranes as well as the inhibition of the active nutrient transport (FRANCIS 2001). Therefore, the presence of different antinutrients in the groundnut cakes prohibits the inclusion of more than 50 percent in the diet otherwise growth performance of fish became depressed (Jackson *et al.* 1982) Additionally, some plant crops, *e.g.* beans or different tubers, may probably not be suitable, because they are grown for direct human consumption and thus be too expensive and valuably to use as fish feed in non-affluent societies.

Nevertheless plant materials are excellent sources of carbohydrates, lipids and even proteins. Compared to animal feedstuffs, plant derived ingredients are less digestible, but also less expensive (Jauncey 1998).

Aside from the just mentioned feedstuffs industrial by-products may also be highly suitable. Mostly these materials are undesirable wastes for the producers and therefore available at low prices and in huge quantities. Suitable by-products are, for example, brewery and distillery wastes, as well as coffee pulp and press cakes as residue from oil extraction.

2.4 Potential Feed Materials identified in the Study Area

The first step towards the enhancement of the 'Whedos' productivity is to identify potential plant and animal products which are suitable for the formulation of supplementary experimental feeds as well as for the application as fertilisation. Therefore, I visited several local markets and mills, the local slaughterhouse as well as the bakeries. The different materials considered being of use together with their prices and seasonal availability are summarized in Table 1.

As indicated in Table 1 all selected material are available the whole year round but differ in their prices according to season. For example cereal brans are cheapest at the beginning of the dry season meaning shortly after harvesting whereas they become more expensive at the beginning of the rainy season when the stocks are almost depleted. Beside the local production, millet and sorghum brans are also imported in high quantities as animal fodder with canoes from Nigeria along the River Niger.

Water macrophytes are available in massive quantities during the inundation in all water bodies. During the dry season they are restricted to the numerous floodplain pools, swamps, rice fields and 'Whedos'.

In the rice growing area of Malanville rice is cultivated the whole year round due to the irrigation water provided by the River Niger. In the villages around Malanville farmers grow rice on the floodplain in accordance with the natural flood but in addition also in the dry season by using the high groundwater table with the aid of motor pumps.

Tab. 1: Potential feed ingredients and materials for fertilisation identified and listed with their prices and seasonal availability. All prices are average values from 2008 and 2009 and partly from 2007.

Material	Price FCFA/kg (€/kg)	Availability	Additional notes
Groundnut cake (*Arachis hypogaea)*	462.1 – 567.1 (0.71-0.87)[1]	All seasons but prices differ significantly	By-product from oil extraction. Also used for the preparation of sauces for human consumption.
Bakery floor sweepings	40 (0.06)	All seasons	Left-over; especially meal but high competition since it is used as pig fodder.
Millet bran *(Panicum sp.)* **Sorghum bran *(Sorghum sp.)*** **Corn bran**	83.3-143.8[1] (0.13-0.22) 83.3-161.0[1] (0.13-0.25) 60.2-136.0[1] (0.09-0.21)	All seasons but prices differ significantly	Left-over after milling but high competition since it is used as animal fodder and in poor households even for human consumption.
Rice bran	0- 16.3[2] (0 - 0.025)	All seasons in different qualities	Left-over after milling. Because of irrigation rice is also cultivated in the counter season. Better quality used as animal feed and in poor households even for human consumption.
Blood	Free of charge	All seasons	Waste product from the slaughterhouse, not used for human consumption or as animal feed.
Fish Trash	Free of charge	All seasons but amount differs	Available on the local fish market after cleaning of the fish, mainly fins, scales, guts and bones.
Azolla (*Azolla africana*) **Water lettuce** (*Pistia stratiotes*) **Water hyacinth** (*Eichhornia crassipes*)	Free of charge	All seasons	In dry season only available on the rice fields and the floodplain pools.
Animal manure	Free of charge	All seasons	Difficult to collect because not stable, thus scattered on a wide area.
Slaughterhouse waste	Free of charge	All seasons	Mainly content of the stomach and intestine.
Rumen content	Free of charge	All seasons	Available in big quantities in the slaughterhouse. Also used for fertilisation of the rice fields.

[1] Price depends on the amount purchased as well as the season.
[2] Price depends highly on the quality of the brans meaning the amount of broken grains. Low quality brans are usually free of charge.
[3] The transport is labour intensive since water macrophytes contain approximately 90 percent of water.

In the town of Malanville there exist dozens of mills for rice and other cereals, and also in the villages there exists at least one principal mill where the local farmers commission their grain harvest. At the mills, the rice bran of low quality (consisting particularly of the husks) are usually free of charge while the higher quality brans are also used as animal fodder and thus demand a small price.

Groundnut press cakes are sold on the local market and also produced on-farm as a by-product of the groundnut cultivation. After grinding and heating of the groundnuts and the skimming of oil, the remaining dough is rolled out, cut into small cubes and fried. These cakes are available in different measurements and the higher the purchase quantity the better the price *e.g.* in 2008 the price on a kilogram basis was 248.50 FCFA (0.38€) when purchasing a 66.4 kg sac while the price increased to an average of 522.16 FCFA (0.80€) per kilogram when buying small units of 160 to 328 grams. Furthermore, prices also fluctuate according to the season.

Additionally, there exist several small bakeries in the town Malanville; thus every day there accumulates some waste consisting particularly of wheat flour that fell on the floor during processing. But farmer esteem the bakery floor sweepings as energy supplementation for their pigs and thus the former free by-product costs 40 FCFA/kg (0.06€) in 2007 and its availability is restricted.

Blood is the most important by-product from the slaughterhouse since all other animal parts except of the stomach and intestine content are destined for human consumption or other purposes. According to the measurements conducted over several weeks during the dry and rainy season the daily average amount of animals slaughtered consisted of 5 zebus, 13 goats and 1 sheep accounting for a total of 53.6 kg of fresh blood (43.5 kg, 9.1 kg and 1 kg, respectively) per day. After separating the coagulated blood from the blood plasma and its subsequent drying and grinding an amount of 10.8 kg of blood meal can be yielded.

Because of the halal slaughter of the ruminants, and their positioning over ditches constructed at each killing floor, the blood is collected and piped to a swamp area in the back yard of the slaughterhouse. Since all effluents are flushed into the local environment without any control and protection their accumulation presents a high risk of contamination for adjacent rice fields and habitations as a consequence of the decomposition of the organic waste and the development of dangerous pathogens as well as malodour.

The same is also valid for the fish trash arising through the disembowelling and cleaning of the fish on the market as well as on the household level. There exist no waste management systems at all and waste materials are just accumulated on a huge hill at the border of the town or flushed into the open drains constructed along the streets, thus representing a perfect source of pathogenic contamination.

2.5 Criteria for the Selection of Appropriate Ingredients

The choice of suitable material as ingredients for a supplementary feed is subject to a number of criteria. Since rural households usually suffer from low purchasing power, feed materials must be available at little or no costs. Moreover, the feedstuff must be available both locally and also the year round; if the latter is not the case it should at least be storable for the time of shortage of supply. Thus, materials produced for human consumption or used as animal feed are mostly not suitable because of the high demand that leads to raised prices and limits their availability. Another important criterion is that the requirements on handling and processing should be minimal and easy in order to keep the amount of labour and other expenses as low as possible. Finally, the nutrient content and palatability of the material is important; thus material with high protein and low fibre contents should be favoured.

To test this presumption the materials collected in the study area and presented in chapter 4.2.4 were further analysed for their nutritional value. The different feed materials are divided into feeds of animal origin and those of plant origin. Materials considered as suitable pond fertilizer are listed separately. Their chemical compositions are summarized in Table 2. The methods applied for the analyses were in accordance to AOAC (1990) and Smedes (1999) and are defined in Appendix 1.

As can be noted in the table, for some materials their nutrient compositions vary considerably. This can be the result of the species, the culture area, climate, intensity and kind of fertilization, harvest practice, processing and storage.

Finally, rice bran, groundnut cake, blood meal, fish trash and *azolla* became the material of choice for the formulation of the supplementation while the rumen content was considered appropriate as pond fertilizer.

Low quality rice bran was used since it is free of charge, available in sufficient quantities and not used as fodder for other animals. Although the other cereal brans analysed showed higher nutritional values, rice bran was used as base material because all other brans are more expensive since they are already used as fodder for other animals, particularly ruminants, and even as food in poor households and thus their demand is quite high. Also the bakery floor sweepings are not suitable because they are used as pig feed meaning the available quantity of 125 kg per week is not sufficient to serve for feeding pigs and fish.

Tab. 2: Chemical composition of some potential feed ingredients collected in the study area Malanville.

Samples	Notes	DM	Ash	CP	CL	GE (MJ/kg)
			as % of DM			
		Plant origin				
Maize bran		88.8-91.8	2.4-6.3	10.2-14.5	3.84-15.4	17.9-20.5
Millet bran		90.9	13.2	17.7	7.6	19.5
Rice bran	High quality fine material	90.3-92.7	20.7-28.2	5.9-7.9	5.1-6.9	14.4-15.9
Rice bran	Low quality, coarse material, particularly husks	93.0-93.1	22.2-22.6	4.7-5.1	4.4-4.5	15.8
Bakery floor sweepings	Wheat meal	92.0	17.1	14.6	1.4	15.0
Groundnut cake (*Arachis hypogaea)*		89.7-94.2	4.2-4.6	42.6-49.0	15.7-22.6	24.0-24.9
Water fern *(Azolla africana)*		94.0	34.0	17.6	4.2	11.6
Water lettuce	Roots	94.7	63.3	7.6	1.6	4.8
(Pistia stratiotes)	Leaves	92.2	28.8	12.6	3.0	11.3
Water hyacinth	Roots	93.9	38.4	10.0	2.6	10.1
(Eichhornia crassipes)	Leaves	92.7	30.2	14.1	3.1	11.4
		Animal origin				
Slaughterhouse waste	Particularly stomach and intestine content	92.1	21.3	15.6	2.6	14.7
Blood meal		88.3 - 89.2	1.7-8.2	89.1-94.2	1.2-2.0	22.3-23.0
Bone meal		98.0	94.5	4.0	0.5	n. d.
Fish trash	Particularly bones, fins and viscera	90.9-93.3	28.1-58.3	21.1-53.0	11.1-14.6	11.8-16.6
		Fertilizer				
Goat manure		93.4	17.4	20.8	6.0	17.7
Cow manure		94.4	29.7	10.3	3.5	13.2
Rumen content		91.6-92.2	17.5-25.7	8.4-17.0	1.8-5.7	14.9-17.0

DM = Dry matter; CP = Crude protein; CL = Crude lipid; GE = Gross energy.

In order to achieve the best growth performances several protein sources were chosen and formulated into different kinds of feeds. Blood meal was chosen as protein source because it is very high in protein content (89.1-94.2 percent), free of charge and not used for other purposes. Furthermore, it is fresh and daily available not only at the local slaughterhouses but also at household and market level.

However, ingredients of animal origin are susceptible to fast deterioration as a result of their high protein content. But the occurrence of deterioration can be reduced by mixing those products with dry components (JAUNCEY 1998); thus the blood was sun-dried on aluminium sheets, converted to meal and mixed with the rice bran *i.e.* with the other dry materials used for the particular feed.

Although not free of charge, groundnut cake was also chosen as protein source since it showed good growth rates of *Clarias* in several former studies (POUOMOGNE 1995, NYINA-WAMWIZA *et al.* 2007) and thus it was the goal to test if the additional purchase costs will be paid off by enhanced fish production and incomes. In order to avoid attacks from fungi which release toxic metabolites, *e.g.* aflatoxins from *Aspergillus flavus* contamination (JAUNCEY 1998), it was sun-dried, mixed with the other dry materials and stocked under dry conditions and low air humidity.

Fish trash was collected on the local market but additionally it is also available in each fisherman household. The material is very suitable since its amino acid profile is in accordance with the requirements of the fish (JAUNCEY 1998). Furthermore, it is available for free and will also increase the palatability of the feed. The trash was boiled briefly in water to destroy the corpus of pathogens, subsequently sun-dried and prepared as meal.

The last material used as protein source was the water fern *Azolla*. The plant is available in huge quantities especially during the rainy season and prepared as meal it can be stocked easily. However, although it is free of charge, transport costs are usually quite high since water macrophytes contain typically around 94 percent of water (JAUNCEY 1998). Therefore, to ensure low effort for transporting the plants it is advisable to dry them directly at the place of collection. After drying it was also ground to powder, mixed with the other materials and stored under low air humidity.

In terms of pond fertilisation, animal manure has a high potential (LITTLE & MUIR 1987) and is in general available in huge amounts in the whole region. But since animals are not farmed indoors their dung is scattered over a big area and therefore difficult to collect. Consequently, we chose the stomach contents as means of fertilisation since it is accumulated in extensive amounts in the back yard of the local slaughterhouse of Malanville and thus less labour intensive to collect. These slaughterhouse waste products are free of charge and available to everybody. According to the measurements conducted over several weeks an amount of 164 kg of stomach content accumulates every day. Some innovative farmers also use this organic material as fertilizer for their rice fields but nonetheless it is not considered as scarce.

Finally, all these materials were mixed in different relation and quantities to form the test diets for the *Clarias* and fed in two different trials in 2008 and 2009 in the 15 experimental 'Whedos' constructed on the rice cultivating area of Malanville. Further details on the construction of the experimental ponds are given in Appendix 2.

3 *CLARIAS GARIEPINUS*

3.1 General Information on *Clarias gariepinus*

The feeding trials that are described in the following sections were conducted by using *Clarias gariepinus* (Burchell 1822) as experimental fish (Fig. 1). The species is also known as sharptooth catfish in aquaculture (Okeyo 2003) and belongs to the:

Kingdom: *Animalia*
Phylum: *Chordata*
Class: *Actinopterygii*
Order: *Siluriformes*
Family: *Clariidae*
Genus: *Clarias* (Scopoli 1777)

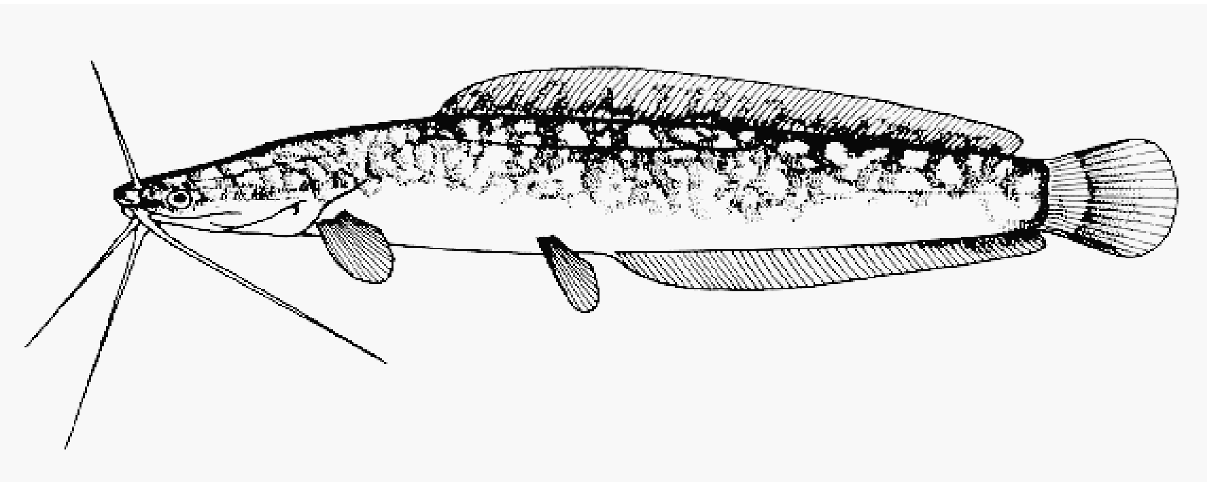


Fig. 1: *Clarias gariepinus* Source: Eccles 1992

Within the Clariidae, *Clarias,* with 57 species, is the most species-rich genus. Before a major systematic revision carried out by Teugels (1982a, 1982b, 1984) more than 100 species had been described for the genus *Clarias*. Before 1982, systematic studies on the large African catfish species (subgenus *Clarias*) recognized five species but after its revision only the species *C. gariepinus* and *C. anguillaris* were found. Consequently, the former species *C. capensis*, *C. lazera*, *C. mossambicus* and *C. gariepinus* are now specified as *Clarias gariepinus* (Teugels 1986).

Clarias gariepinus belongs to the group of 'air-breathing' fish that have considerable resistance to low dissolved oxygen concentration and are termed 'blackfish' in Asia. They inhabit floodplains or the floating vegetation mats fringing river channels, but can also occur in fast flowing rivers and rapids (DAGET 1959; TEUGELS 1986, WELCOMME & DE MÉRONA 1988).

Spawning has one clear seasonal peak and takes place during the rainy season in flooded grassland. Therefore the fishes make lateral migrations towards the inundated plains. Usually they will return to the river or lake soon after breeding whereas the juveniles remain in the flooded area and migrate to the lake or river when they reached approximately 1.5 to 2.5 cm (WITTE & WINTER 1995).

3.2 FEEDING BEHAVIOUR AND NUTRIENT REQUIREMENTS OF *CLARIAS GARIEPINUS*

In the wild, *Clarias gariepinus* is a bottom feeder but occasionally it also feeds at the surface (BRUTON 1979a, b; TEUGELS 1986). GROENEWALD (1964) reported that *Clarias gariepinus* is a general carnivorous feeder and that the intake of non-animal material has to be considered as incidental. However, their omnivorous feeding habit was confirmed by UYS (1989) who found out that *Clarias* possesses a protease similar to carnivorous species, starch digestion capability similar to herbivores and lysozyme, and alkaline phosphatase as in detritivores. Furthermore, they are also able to filter small zooplankton and algae with their numerous branchiospines (WORTHINGTON & RICARDO 1936).

The species forages particularly at night on a wide variety of prey including insects, plankton, invertebrates, crustacean, vegetal detritus and fish but also young birds, rotting flesh and plants (BURGESS 1989; MICHA 1973; BRUTON 1979a; MUNRO 1967). *C. gariepinus* can be considered as opportunistic omnivore since the importance of a certain food type varies from area to area according to the availability (DE MOOR & BRUTON 1988; VAN WEERD 1995).

Their dietary requirement for protein seems to be in the order of 40 percent and for energy between 13 and 17 kJ gross energy/gram, whereas the optimum fat percentage at a dietary protein level of 42 percent is between 10 and 12 percent (MACHIELS & HENKEN 1985; UYS 1989; DEGANI *et al.* 1989).

The broad spectrum of digestive capability permits several feeding methods, *e.g.* hunting, bottom feeding, surface and even filter feeding, and allows a high degree of adaptability to different habitats (MWEBAZA-NDAWULA 1984).

However, studies conducted in intensive monoculture systems recorded a relatively high protein requirement of *C. gariepinus* (DE GRAAF & JANSSEN 1996).

3.3 HISTORY OF THE AQUACULTURE OF *CLARIAS GARIEPINUS*

C. gariepinus, with its almost Panafrican distribution from the Nile to West-Africa and from Algeria to South Africa, is the most commonly cultured African catfish (FERRARIS 2007, DE GRAAF & JANSSEN 1996). But the interest in culturing African catfish species is relatively new and was stimulated by the success of the husbandry of the Asian catfish *Clarias batrachus* and *C. macrocephalus.*

Of fundamental value to aquaculture is the presence of an accessory breathing organ that enables *Clarias* to breathe air (MOUSSA 1957; TEUGELS & GOURÈNE 1998). This organ is composed of modified gill filaments attached to two of the gill arches and supported by strong cartilage to prevent their collapse when the fish is out of the water (GIETEMA 1999). As a result, *Clarias* is highly adapted to dwell in floodplain pools and marshes and is not in danger of nocturnal suffocation through deoxygenation of ponds or as a result of heavy fertilization or feeding (JACKSON 1988).

The first intensive research programs on the culture of *C. gariepinus* began in Egypt in the 1960s (EL BOLOCK 1969) and then spread to various other African countries, *e.g.* the Central African Republic, Cameroon and South Africa. The species was first bred in ponds in South Africa in the late 1960s and in 1970 their potential for aquaculture was investigated in Central Africa. The species has also been introduced to Asia for hybridization with Asian Clarias (LEGENDRE & LEVEQUE 2006), where it represents a severe threat to the local fish fauna (TEUGELS & GOURÈNE 1998). However, in this period the research on *C. gariepinus* was on a relatively low level, but several efforts on their culture initiated since the mid 1970s (particularly in the Netherlands, South Africa, Belgium, Central African Republic, Nigeria and Ivory Coast) resulted in the fast development of the technology throughout Africa (HECHT *et al.* 1996).

Generally, breeding is relatively simple and possible in grass-bottomed ponds and might constitute an appropriate method for culture to market size in growing ponds. However, since this method usually results in only low survival rates it is wasteful and space-consuming. Therefore, modern intensive systems usually induce spawning by hormone injections (JACKSON 1988).

Another important development in regard to the farming of African catfish was the successful hybridization of the giant catfish *Heterobranchus longifilis* with *C. gariepinus* resulting in better growth rates (JACKSON 1988). Moreover, *Clarias* is also successfully stocked as predator in polyculture systems to control the excessive reproduction rate of *Tilapia* spp. that leads to high competition for feed resulting in poor growth rates and the consequent harvest of small fish (VIVEEN *et al.* 1985). Through predation the low valued tilapia fingerlings are replaced by the growth of the higher valued catfish and in addition the adult tilapia reach bigger sizes as their growth rate increases (DE GRAAF & JANSSEN 1996).

As a result of its high adaptation ability and omnivorous feeding habit *C. gariepinus* is very suitable for simple farms as well as intensive hatchery culture. However, in intensive monoculture best growth rates were obtained by feeding formulated diets containing 35-42 percent crude protein together with a digestible energy content of 12 MJ/kg. Table 3 summarize the recommended dietary nutrient level for C. *gariepinus* growers according to the ADCP (1983).

Tab. 3: Recommended dietary nutrient levels for C. *gariepinus* growers (according to ADCP 1983 and DEGANI *et al.* 1989).

Nutrients (percentage of dry matter)		***C. gariepinus* growers**
Digestible protein/Crude protein		30 – 35/40
Digestible energy	(kcal/g)	2.5 – 3.5
Ca	(min-max)	0.5 – 1.8
P	(min-max)	0.5 – 1.0
Methionine plus Cystine	(min)	0.9
Lysine	(min)	1.6

But, with regard to the nutrient requirements listed in the table it should be borne in mind that these are recommendations for intensive monoculture systems where fishes are exceptionally dependant on artificial, complete diets while natural food supply does not play any role in their daily feed intake. Furthermore, the high input of feed requires a regular exchange of water in order to prevent the accumulation of waste from uneaten feed and excreta.

Therefore, with regard to traditional aquaculture systems the feeding of complete and thus expensive diets is not appropriate. Instead, natural food production is mostly improved by fertilization of the pond or the fishes are fed with low quality agricultural by-products. The supplementary feeds are applied to improve growth of fish, while natural food organisms are still their primary source of nutrients (GIETEMA 1999). Even though supplementary feed will not be ingested directly by the fish it enhances natural productivity of the pond (NEW *et al.* 1994).

According to (HECHT *et al.* 1996) Clarias is undoubtedly a very appropriate species for aquaculture production.

3.4 WHY IS *C. GARIEPINUS* APPROPRIATE FOR 'WHEDO' STOCKING AND WHY USED FOR THE FEEDING TRIALS IN MALANVILLE?

The most important reason for using Clarias for stocking is their high adaptability *e.g.* their air-breathing capability and wide tolerance vis-à-vis turbidity and strongly differing pH values (BRUTON 1988), enabling them to withstand the highly variable and unfavourable environmental conditions prevailing in the 'Whedos'. In addition, studies on fish diversity of the 'Whedos' and the biomass harvested at the end of the dry season already highlighted the importance of *Clarias* sp. in the total annual catch.

During the development of this project, it was clear that the acceptance of the results would be helped by the use of indigenous fish species which have already made a local contribution to aquaculture, such as *Clarias*.

Generally, the introduction of exotic species should be avoided because of the risk that they might escape into the local ecosystem. Once arrived, they will compete with indigenous species. This can lead to the elimination of the native species *e.g.* because of a lack of natural enemies or high adaptation potential of the exotic species. Beside the decline of species diversity it might also affect the whole ecosystem because of fundamental changes in the trophic chain. Probably the most famous example for a destroyed ecosystem is the introduction of *Lates niloticus* into Lake Victoria leading to the disappearance of numerous endemic cichlids (BRUMMETT & WILLIAMS 2000) followed by an increasing eutrophication and consequently by decreasing dissolved oxygen concentration (LÉVEQUE 2006).

C. gariepinus is an indigenous fish species dwelling in swamps and floodplain pools and able to tolerate temperatures ranging from 7 to 38°C, with a preference for temperatures between 28° and 30°C (KARANTH & SELVARAJ 2005). The resistance towards high temperatures is of considerable importance with regard to the high temperatures prevailing in the 'Whedos' sometimes reaching more than 32 degrees Celsius.

C. gariepinus is an herbivorous/omnivorous fish that exhibits good growth rates on a broad range of food items. This characteristic is helpful, because feeding on naturally available food reduces the cost of elevation. Apart from the wider ecological aspects, the use of aquafeed based on high protein ingredients such as fish meal is economically not profitable in small-scale aquaculture systems where fish prices are too low to cover the costs of imported or expensive feed components. It is for these reasons that omnivorous species such as *C. gariepinus* play an important role in rural aquaculture.

Another very important aspect is the fact that these fish are well known and highly appreciated as food by the indigenous population in the commune of Malanville. *Clarias* has a high eating quality because of its boneless fillets and is also rich of unsaturated fatty acids having a high fat content of approximately 2.5 % (KARANTH & SELVARAJ 2005). As refrigeration is very rare in the rural households, *Clarias* is very popular as a dried/smoked product and because of their physical robustness and air-breathing habit, if kept wet, they can be transported alive to markets over considerable distances (ANETEKHAI *et al.* 2004).

However, apart from *Clarias* I also recorded other adapted species such as *Protopterus annectens, Polypterus sp.* and *Heterotis niloticus* surviving the harsh conditions of the 'Whedos', thus they might also be suitable for cultivation. But in comparison to *Clarias* sp. they constitute only a minor part of the total biomass harvested. Additionally, there exist further arguments against their cultivation in the 'Whedos'; for example the carnivorous feeding habit of *Polypterus sp.* (particularly insects and also small fish) and the problem that *H. niloticus* do not do well in small and crowded ponds (LAUZANNE 1988; JACKSON 1988). Furthermore, the species *P. annectens* is not highly appreciated by the population because of its slimy and snake-like appearance and so only achieves low prices in the market.

Consequently I considered *C. gariepinus* as most suitable species for culturing in the 'Whedos' and therefore decided to conduct the feeding trials using them as the experimental fish.

4. EXPERIMENTAL FEEDING TRIALS

4.1 General Introduction

This work delves into the recently developed 'Whedo'-aquaculture-system in the rural community of Malanville (North Benin). 'Whedos', locally known as 'Tschifi dais' (TD) are small artificial depressions (median surface area 200 m^2; n = 73) that are dug within the floodplain. A proportion of fish migrating into the inundation zone get trapped when the plain is drained *i.e.* when fish holes are isolated from the river during the dry season. Several months post flooding the owners will exploit their TDs. Although, this is a traditional practice of fish rearing along the Ouémé River Valley in the south of Benin, it was not known in Malanville before 1998; thus TDs differ significantly from the 'Whedos' in their dimension, fish species and management practices (see Lalèyè *et al*. 2007; Welcomme *et al.* 2006; Hauber *et al.* 2011a).

However, in the last decade the study region experienced a kind of 'blue revolution' and since 1998 more than 464 of these fish holes were constructed without any financial support, thus highlighting their esteem by the indigenous population.

Certainly the most important factors for the fast acceptance of this system are the existing knowledge of post-flood wetland fisheries as well as the low investment needed for its installation. Additionally, local fishermen, fishmongers and consumers complain about the reduction of the total catch, decreasing average size of fish as well as changing fish communities including the disappearance of some species. As a result of the disastrous state of the main rivers (Niger and Sota), fishermen need to increase their efforts to catch one unit of fish resulting in lower incomes and thus forcing them to diversify their sources of income.

Fish are often highly concentrated in TDs and the annual biomass harvested averaged 3 tons/ha in 2008 and 2.1 tons/ha in 2009 (Hauber *et al.* 2011a). In addition, local farmers are lacking knowledge on appropriate feed ingredients and the importance of a regular feeding regime. Thus, fish are only fed irregularly with material of low nutritional value, mostly at the beginning of the flood to attract fish or cause them to stay in the fish holes. By now, rice bran is by far the most used supplementary feed since it is free and easily available from the numerous local mills. As a consequence of the high fish densities and the inadequate food supply, 70 percent of the individual fish harvested, mainly *Clarias* sp., averaged a weight of only 40 grams.

Although TOKO *et al.* (2007) obtained good growth rates by feeding a diet containing 34 percent of protein to *C. gariepinus* and *Heterobranchus longifilis* reared in local 'Whedos', the use of commercial fish meal, maize meal and palm oil is not appropriate for application in Malanville since these materials are either not available, used for human consumption or ecologically questionable. Additionally, the low fish prices at the local markets do not allow the use of high quality feed and thus feeding should aim on the supplementation of the natural food supply by providing energy rich materials (JANTRAROTAI & JANTRAROTAI 1993). Hence, prior to the feeding trials market analyses and investigations on locally available by-products were conducted. The materials selected were rice bran (RB), blood meal (BM), groundnut press cake (GPC), fish trash (FT) and *azolla* meal (AM).

Generally, we aimed on the determination of a suitable and cheap supplementation that might enhance growth rates and thus resulting in additional income of the farmers. Therefore, six low-protein diets were fed in two experiments in 2008 and 2009 to test their effects on the growth of *Clarias gariepinus* fingerlings.

Moreover, we wanted to investigate the nutritional value of rice bran and the performances of *Clarias* fed a diet containing *azolla* meal. Although *azolla* was already successfully tested on Tilapia spp. (see *e.g.* ABOU *et al.* 2007; NAEGEL 1997) data on the impact on *C. gariepinus* are missing.

4.2 MATERIAL AND METHODS

4.2.1 FACILITIES AND FISH

Feeding experiments were conducted in Malanville (Northern Benin) in 12 earthen ponds with a dimension of 7 m x 4.5 m (31.5 m^2), comparable to the locally common TDs but with the only exception that our ponds were protected against the annual flood. The 'Whedos' were only supplied by groundwater with a mean water depth of 75 to 95 cm and 61 to 79 cm (N 11°52.112' E 003°24.750') in 2008 and 2009, respectively. In 2009 the water table declined from an average depth of 84 to 69 cm in the course of the dry season.

All TDs were fertilized prior to the experiment by placing two perforated bags each filled with 3.5 kg sun-dried rumen content in two corners of the pond for two weeks.

Each pond was stocked with 158 fingerlings of *C. gariepinus* (5fish/m^2) averaging 26.9 g ± 1.4 in 2008 and 29.5 g ± 2.0 in 2009. For the first trial in 2008 fingerlings were obtained from the Royal Fish Farm in Porto-Novo and transported for about 8 hours to the study site in aerated plastic bags. In 2009, fingerlings were purchased at PPP ('Projet Piscicole de Parakou'), a private fish farm approximately 4 hours away from the study site.

Fish were later transferred into the experimental 'Whedos' and acclimated for four days by feeding rice bran. The studies were based on a randomized design consisting of four treatments; each with three replicates.

Fish were sampled bi-weekly to control growth and adjust the daily amount of feed for the following two weeks. In the case of mortalities the amount of feed was adjusted according to the weight of the respective fish. For control weighting each pond was seined to achieve a minimum of 25 percent of the stocked fish. Individual mean weight per pond was calculated and the value was used to compute the daily feed ration. At the day of control fishing, the fish were not fed.

In 2008, the 'Whedos' were harvested after 10 weeks by seining several times. In 2009, *Clarias* were fed for a period of 20 weeks. Subsequently, the 'Whedos' were drained completely to catch the resting fish that were hiding in the bottom mud. Fish were counted and the total weight recorded. 25 percent of fish were measured individually.

Growth performance and nutrient utilization of the diet were assessed in terms of specific growth rate (SGR), body weight gain (BWG), feed offered (FO), feed conversion efficiency (FCE), protein efficiency ratio (PER) according to OLIVERA-NOVOA *et al.* (1990). The respective formulae are listed below:

- BWG (g)	final body weight, g – initial body weight, g
- FO (g)	total dry matter of feed given over the experimental period
- SGR [%]	[(ln final body weight, g – ln initial body weight, g)/duration of the trial, days]*100
- FCE	dry feed fed, g/live body weight gain, g
- PER	wet body weight gain, g/crude protein fed, g

4.2.2 FEED AND FEEDING IN 2008

Rice bran and fresh blood were collected at the numerous local rice mills and the local slaughter house, respectively. The groundnut cake was bought on the local market.

The blood was sun-dried on aluminium sheets for approximately two days. Before mixing, the blood and groundnut press cake were ground.

Proximate analyses of the different materials and the diets were carried out according to the description of the Association of Official Analytical Chemists (AOAC 1990) and SMEDES (1999) and results are presented in Table 4. Crude protein was analysed with an Elementar Vario MAX CN analyzer (thermal oxidation technique). For determining the gross energy (GE) content (MJ/kg) a bomb calorimeter (IKA-Calorimeter C700 Isoperibolic) based on benzoic acid as standard was used.

Table 4: Proximate composition of the feed ingredients
(expressed as percentage of dry matter or of MJ/kg) and their local prices (FCFA/kg).

Ingredients / Diets	Dry Matter	Crude Protein	Crude Fat	Ash	Gross Energy (MJ/kg)	Price (FCFA*/kg)
		as % of Dry Matter				
Rice bran	93.1	4.4	4.9	22.4	15.8	1.1
Blood meal	89.2	94.2	1.2	8.2	23.0	116
Groundnut cake	89.7	42.6	22.6	4.6	24.0	341
Rumen Content	92.2	8.4	1.8	25.7	14.9	n.r.

*1€ = 655.96 FCFA; n.r. = not recorded

Four diets were formulated; their composition is given in Table 5. Rice bran was used as control feed (C) since it is the common feed material used by the locals. Fish were further fed with a mixture of rice bran and 10 % blood meal (T1), a mixture of rice bran with a ration of 10 % BM and 10 % of groundnut press cake (T2) and a mixture of rice bran with a ration of 10 % BM and 20 % of GPC (T3).

Tab. 5: Formulation of the experimental diets.
The composition of ingredients is given as percentage of dry matter.

Diets / Ingredients	Control	Treatment 1	Treatment 2	Treatment 3
Rice bran	100	90	80	70
Blood meal	0	10	10	10
Groundnut cake	0	0	10	20
TOTAL	100	100	100	100

Fish were fed daily at 5 percent body weight divided in two applications at 7 a.m. and 6 p.m. for 10 weeks. The different dry and ground feed ingredients were mixed and prepared with water to form palm-sized balls sinking to the ground as it is done by the locals.

4.2.3 FEED AND FEEDING IN 2009

As in 2008 rice bran and fresh blood were collected at the numerous local rice mills and the local slaughter house, respectively. The fish trash is free of charge and available daily at the local fish market since consumers often gut their fish directly on-site. During the rainy season *Azolla africana* is available in huge quantities on the floodplain; mostly restricted to depressions, floodplain pools as well as the TDs.

Before drying, fish trash was boiled for a few seconds in hot water. Afterwards, the blood, fish trash and *azolla* were sun-dried for approximately 2 days and ground prior to the feed preparation.

Proximate analyses of the different materials and the feeds were carried out in the same way as already described in the previous section and are shown in Table 6.

Four diets were formulated; their compositions are given in Table 7. Rice bran was used as control feed (C), since it is the common feed material used by the locals. Fish were further fed with a mixture of rice bran and 10 % blood meal (T1), a mixture of rice bran with a ration of 19 % BM (T2) and a mixture of rice bran with a ration of 30 % fish trash and 20 % of *azolla* (T3).

Tab. 6: Proximate composition of the feed ingredients
(expressed as percentage of dry matter or of MJ/kg) and their local prices (FCFA/kg).

Ingredients / Diets	Dry Matter	Crude Protein	Crude Fat	Ash	Gross Energy (MJ/kg)	Price (FCFA*/kg)
		as % of Dry Matter				
Rice bran	93.3	4.9	5.4	26.5	15.0	1.1
Blood meal	88.8	91.7	1.6	5.0	22.7	116
Fish Trash fresh	90.9	53.0	11.1	28.1	16.6	n.r.
Fish Trash prepared	93.3	21.1	14.6	58.3	11.8	2264.3
Azolla	94.0	17.6	4.2	34.0	11.6	84

*1€ = 655.96 FCFA; n.r. = not recorded

For comparative evaluation T2 was repeatedly fed to *Clarias* because in 2008 growth performance of fish showed a wide standard deviation amongst the three replicates. Moreover, it will be possible to compare the ration of 10 percent of blood meal with treatment 3 containing the double amount (19 %) of blood meal.

Fish were fed daily at 5 % body weight divided in two applications at 7 a.m. and 6 p.m. for 20 weeks. The different dry and ground feed ingredients were mixed and prepared with water to form palm-sized balls as already applied in 2008.

Tab. 7: Formulation of the experimental diets; composition of ingredients in dry matter.

Diets / Ingredients	Control	Treatment 1	Treatment 2	Treatment 3
Rice bran	100	90	81	50
Blood meal	0	10	19	0
Fish Trash	0	0	0	30
Azolla	0	0	0	20
TOTAL	100	100	100	100

4.2.4 Chemical Analyses

Samples for water parameters were taken weekly at 7 a.m. and 1 p.m. at a depth of 20 cm from two different sites of the pond and pooled to provide an integrated sample. Temperature (°C) and dissolved oxygen concentration (DO) were measured with DO-100 from Voltacraft (accuracy ± 0.4 mg/l), while conductivity and pH-value were analysed applying the HI98129 Combo from Hanna (accuracy ± 1µS/cm or 0.01,). Furthermore, in 2009 nitrite, nitrate, ammonia as well as total phosphorus (P) concentrations (all measured in mg/L) as well as total hardness and alkalinity (mg/L $CaCO_3$) were analysed with the help of colorimetric test kits (Macherey-Nagel). Mean values for the morning and early afternoon analyses are summarized in Table 8 for 2008 and in Table 9 for 2009.

Tab. 8: Water quality in experimental ponds for the duration of the experiment in 2008

Time / Water parameters	Morning 7 a.m.				Early afternoon 1 p.m.			
	Average	Min	Max	SD	Average	Min	Max	SD
Temperature (°C)	26.8	26.4	27.1	0.2	29.4	29	29.7	0.2
Dissolved Oxygen (mg/L)	2	1.20	3.60	0.6	2.5	1.78	3.95	0.2
pH	6.4	5.7	6.8	0.4	6.5	5.7	6.9	0.4
Conductivity (µS/cm)	186	118	297	56	186	112	300	58

SD - Standard deviation

In 2008, dissolved oxygen (DO) concentration was in general low and increased only slightly in the course of the day. This was the result of the high clay turbidity of the water and thus a Secchi disk depth of only 1cm, reflecting the turbidity of several local TDs. Moreover, DO concentrations decreased from the first to the last week of the experiment: from 3.5 mg/L ± 0.98 to 0.9 mg/L ±0.4 in the morning and from 3.6 mg/L ± 0.9 to 1.9 mg/L ± 1.2 in the early afternoon. The most plausible reason was the high organic load as a result of the daily input of feed and the associated higher decomposition rate.

The pH was stable during the duration of the trial while conductivity increased slightly.

Although, there were significant differences regarding the water quality variables among the 'Whedos' they all remained in the range for *Clarias* production throughout the period (VIVEEN *et al.* 1985; YONG-SULEM 2006; FROESE & PAULI 2010).

Tab. 9: Water quality in experimental ponds for the duration of the experiment in 2009

Water parameters / Time	Morning 7 a.m.				Early afternoon 1 p.m.			
	Average	**Min**	**Max**	**SD**	**Average**	**Min**	**Max**	**SD**
Temperature (°C)	27.7	27.1	28.3	0.5	31.0	29.9	31.8	0.6
Dissolved Oxygen (mg/L)	1.7	0.9	1.2	0.4	3.7	2.3	6.9	1.8
pH	7.1	6.7	7.3	0.2	7.1	6.8	7.4	0.2
Conductivity (µS/cm)	361	261	558	105	364	263	566	107
Ammonium (NH_4) (mg/L)	0.8	0.13	2.4	0.9	n.r.	n.r.	n.r.	n.r.
Nitrate (NO_3) (mg/L)	4	3	6	0,.9	n.r.	n.r.	n.r.	n.r.
Nitrite (NO_2) (mg/L)	0.1	0	0.2	0	n.r.	n.r.	n.r.	n.r.
Total Phosphorus (mg/L)	0.3	0,2	0.4	0.04	n.r.	n.r.	n.r.	n.r.
Alkalinity (mg/L CaCO3)	67	20	140	40	n.r.	n.r.	n.r.	n.r.
Total Hardness (mg/L CaCO3)	89	61	122	20	n.r.	n.r.	n.r.	n.r.
Secchi Disk Depth (cm)	7	1	13	4	n.r.	n.r.	n.r.	n.r.

SD - Standard deviation; n.r. - not recorded

Because of the prevailing Harmattan in February 2009 the water temperature only averaged 23.5°C but increased in the following weeks. DO concentration decreased from the first to the last week of the experiment from 3.3 mg/L ± 0.8 to 0.9 mg/L ±0.4 in the morning and from 4.8 mg/L ± 1.1 to 2.1 mg/L ± 1.9 in the early afternoon. The decrease in dissolved oxygen concentrations is probably the result of the higher amount of oxygen needed for the decomposition of the feed that accumulated at the bottom of the 'Whedos'.

Ammonium concentrations increased in the course of the experiment showing the highest concentration in the ponds that belonged to treatment 3 meaning the diet containing the highest percentage of protein. However, differences were not significantly different. Nitrate, nitrite and total phosphorus only increased slightly showing no differences among the treatments.

The pH remained stable during the experiment while conductivity increased from 295 µS/cm ± 95 in the first week to 411 µS/cm ± 139 in the last week of the experiment.

Furthermore, while values for total hardness of the pond water were constant, alkalinity decreased significantly and resulted in an average of only 17.8 mg/L $CaCO_3$ at the end of the experiment; thus did not conform to the desired alkalinity level for most aquaculture species of 50-150 mg/L $CaCO_3$ and even not to the minimum level of 20 mg/L $CaCO_3$ (WURTS 2011). However, all other water quality parameters remained in the range for *Clarias* production throughout the period (VIVEEN *et al.* 1985, YONG-SULEM 2006, FROESE & PAULI 2010).

4.2.5 STATISTICAL ANALYSIS

The software used for the statistical analysis was STATISTICA 9 (Version 9; Statsoft Inc., Tulsa, USA). Data were first tested for normal distribution by applying the Shapiro-Wilks Test (SHAPIRO, WILK & CHEN, 1968). Variances homogeneity was checked with the help of the Hartley test (DAGNELIE 1975). For evaluating the water quality parameters we used the non parametric Kruskal-Wallis Test (SIEGEL & CASTELLAN 1988). Growth performance data were subjected to a one-way analysis of variance (ANOVA) and the significance of the differences between the mean was tested using Duncan's multiple range test ($P < 0.05$) (DUNCAN 1955). However, data for the protein efficiency ration (PER) were normalized by log transformation before subjected to the ANOVA. The values are expressed as means ± standard deviation.

4.2.6 ECONOMICS EVALUATION

For economical analyses, the results of the respective diet were extrapolated to one hectare and additionally to the average natural stocking density of 2 tons/per hectare (HAUBER *et al.* 2011a).

The costs of feed ingredients were based on our market surveys regularly conducted from 2007 to 2009. The prices of materials not available on the local market and for the experimental diets are calculated by comprising the time needed for collecting, transportation and processing. The calculation of labour cost is based on the assumption that one man-hour is 250 FCFA (0.40 €) which was the common salary in 2008 and 2009 in Malanville.

Values of total expenditures (TE) consisted of variable costs (VC) and fixed costs (FC). The gross return (GR) is based on the price of 431 FCFA of unprocessed fish (average price of small-sized *Clarias* sold directly on-site after the harvest). Then the following profitability indicators were calculated as listed below:

Net benefit (NB)	GR – TE
Benefit-cost ratio (BCR)	NB/TE
Profit index	Value of fish (FCFA)/Cost of feeding (FCFA)
Incidence of cost (IC)	Cost of feed (FCFA)/Fish produced (kg)

4.3 RESULTS

4.3.1 FEEDING TRIAL 2008

Feed Quality

The composition of experimental diets is given in Table 10. Diets were not prepared to be isonitrogenous or isoenergetic since the study attempted to test whether or not the higher protein content of the diets, meaning the use of high quality feed ingredients, will lead to higher growth rates and if the higher productivity might cover the additional expenses of the diet. Therefore, protein content increased significantly from the control diet (4.4 %) to diet 3 (19.9 %) as a consequence of the higher inclusion level of protein-rich feed ingredients *i.e.* the reduction from 90 percent to 70 percent of rice bran as percentage of dry matter.

Crude ash content was highest for the control diet (22.4 %), which was almost in the same range than that of the diet 1 (21.1 %). In treatment 2 and 3, crude ash content was 19.6 percent and 18.4 percent, respectively. The higher ash content of the control diet and treatment 1 compared to treatment 2 and 3 was the result of the high content of ash presented in the rice bran (22.4 %). Because of the high inclusion rate of rice bran, the ash content was generally high in all treatments.

The content of crude fat was highest in treatment 3 followed by treatment 2, while the control diet and treatment 1 had almost the same lipid level.

The gross energy content increased from the control diet (15.8 MJ/kg) to treatment 3 (17.7 MJ/kg).

Table 10: Proximate composition of the experimental
(expressed as percentage of dry matter or MJ/kg) and their local prices (FCFA/kg) in 2008.

Ingredients / Diets	Dry Matter	Crude Protein	Crude Fat	Ash	Gross Energy (MJ/kg)	Price (FCFA*/kg)
		as % of Dry Matter				
Control	93.1	4.4	4.9	22.4	15.8	1.1
Treatment 1	92.6	12.6	4.8	21.1	16.2	12.6
Treatment 2	92.4	16.7	6.1	19.6	17.0	46.6
Treatment 3	92.0	19.9	7.7	18.4	17,7	80.6

*1€ = 655.96 FCFA

Feed Intake and Behaviour of fish

Fish were fed for a total of 10 weeks. Fish in all different dietary groups consumed the experimental feeds throughout the whole period of time meaning no negative effects were derived from the experimental diets, although the control diet was not consumed as actively as the other diets. Mortality was highest in treatment 3 (20.5 %) containing 20 percent of groundnut cake and differed significantly to all other treatments (Table 11). Survival rate was highest (97.1 %) in the group fed with the control diet *i.e.* solely rice bran.

Growth Performance and Nutrient Utilization

The weekly growth performance and nutrient utilisation of the experimental diets are shown in Table 11 and Figure 2, respectively.

The body weight gain (BWG) in grams and percentage for the control and treatment 1 did not differ, but they were both significantly lower than for treatment 2 and 3.

However, the highest BWG was achieved in the group fed with diet 3 and was significantly higher than the BWG for treatment 2. With regard to the control group fish lost weight after 6 weeks of feeding until the end of the experiment in all replicates. ´Raw data of bi-weekly BWG are summarized in Appendix 3a.

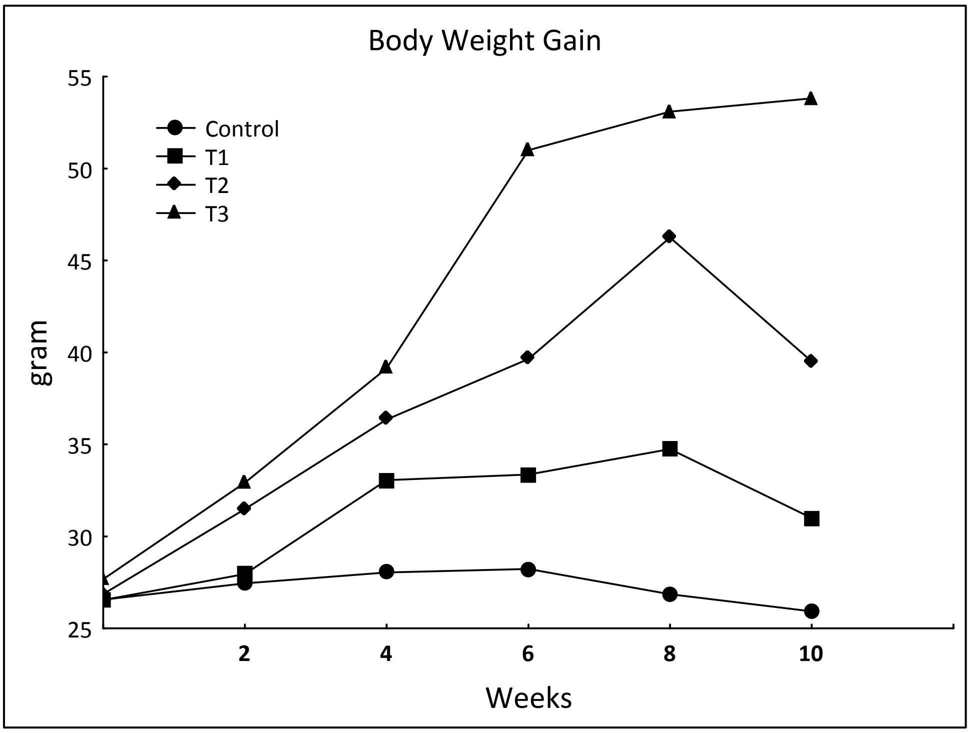


Fig. 2: Weekly growth performance of *C. gariepinus* fed different experimental diets.

The amount of feed offered (FO) did not differ between the control diet and treatment 1 and also not between treatment 2 and treatment 3. But FO differed significantly ($P < 0.05$) amongst these two groups meaning fish of the treatment 2 and 3 obtained more feed than the control group and the group fed with treatment 1.

Protein efficiency ratio (PER) was highest in treatment 3 but did not differ significantly to treatment 2. But both treatments showed significant differences to the control diet and treatment 1.

Table 11: The growth performance and nutrient utilization of *C. gariepinus* fed with different experimental diets.

	Control	Treatment 1	Treatment 2	Treatment 3
IBW (g)	$26.6^{a} \pm 0.9$	$26.5^{a} \pm 2.7$	$26.9^{a} \pm 1.0$	$27.7^{a} \pm 0.7$
FBW (g)	$25.9^{a} \pm 1.2$	$31.0^{a} \pm 4.7$	$39.5^{b} \pm 2.1$	$53.8^{c} \pm 4.5$
BWG (g)	$-0.6^{a} \pm 0.7$	$4.5^{a} \pm 4.0$	$12.7^{b} \pm 1.6$	$26.1^{c} \pm 4.8$
BWG (%)	$-2.4^{a} \pm 2.6$	$16.9^{a} \pm 16$	$47.1^{b} \pm 5.6$	$94.7^{c} \pm 18.9$
SGR (%/d)	$-0.04^{a} \pm 0.04$	$0.25^{b} \pm 0.22$	$0.64^{c} \pm 0.06$	$1.11^{d} \pm 0.16$
FCE	$-0.01^{a} \pm 0.01$	$0.05^{b} \pm 0.05$	$0.12^{c} \pm 0.02$	$0.21^{d} \pm 0.02$
PER	$-0.2^{a} \pm 0.19$	$0.4^{a} \pm 0.38$	$0.7^{b} \pm 0.11$	$1.1^{b} \pm 0.11$
FO (g)	$82.3^{a} \pm 2.7$	$93.4^{a} \pm 9.0$	$108.4^{b} \pm 6.9$	$122.3^{b} \pm 10.7$
Mortality (%)	$2.9^{a} \pm 1.6$	$1.7^{a} \pm 1.8$	$7.2^{a} \pm 3.1$	$20.5^{b} \pm 7.5$
Survival rate (%)	$97.1^{a} \pm 1.6$	$98.3^{a} \pm 1.8$	$92.8^{a} \pm 3.1$	$79.5^{b} \pm 7.5$

IBW = initial body weight; FBW = final body weight; BWG = body weight gain; SGR = specific growth rate; FCE = feed conversion efficiency; PER = protein efficiency ratio; FO = feed offered. Different superscripts accentuate that there are significant differences between the diets ($P < 0.05$).

Specific growth rate (SGR) differed significantly between the treatments showing the best result for treatment 3 whereas the lowest could be observed in the group fed with the control diet (Fig. 3).

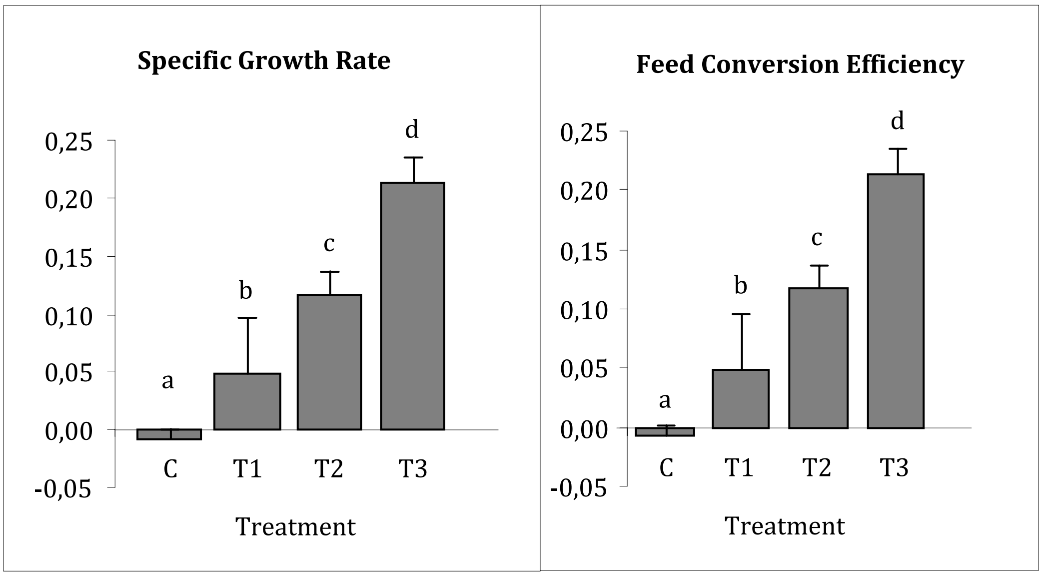


Fig. 3: Specific growth rate and feed conversion efficiency of *C. gariepinus* fed different experimental diets. Different superscripts accentuate that there are significant differences between the diets ($P < 0.05$).

Feed conversion efficiency (FCE) differed significantly among all treatments; while treatment 3 resulting in the best FCE, the control group showed the poorest growth performance (Fig. 3).

Economics Evaluation

Table 12 summarizes the results of the experiment with a stocking density of 5 *Clarias*/m² extrapolated to one hectare, whereas in Table 13 results are given for a stocking density of 2 tons/ha, which was the average biomass harvested in the 'Whedos' investigated in 2008 (HAUBER *et al.* 2011a).

Since both experiments (in 2008 and 2009) showed that fish growth in the control group stagnated as a consequence of insufficient natural food supply we assume that the biomass harvest in the local TDs at the end of the dry season is equal to the natural biomass stocked through natural inundation meaning 2 tons per hectare.

Net profits were directly related to the cost of the respective feed, and total expenditures increased from the control diet with solely rice bran to treatment 3 containing the highest ration of groundnut cake combined with blood meal.

Tab. 12: Benefit-cost analysis for *C. gariepinus* reared with different experimental diets in 2008 (Evaluation based on the stocking density of 5 *Clarias*/m² and on a hectare basis)

Components / Treatment	Control diet	Treatment 1	Treatment 2	Treatment 3
Expenditures (x 1000 FCFA[1]; per ha)				
Fixed costs:				
'Whedo' preparation	20	20	20	20
Fingerling costs [2]	-	-	-	-
Feed cost [3]	4.8	64.6	275.7	531.1
Variable costs:				
Harvest and Maintenance [4]	30	30	30	30
Feeding costs	33.75	33.75	33.75	33.75
Total expenditures (TE)	88.5	148.4	359.4	614.9
Income (x 1000 FCFA[1]; per ha)				
Biomass harvested (kg)	1259.3	1525.1	1844.1	2152.7
Gross return [5] (GR)	542.8	657.3	794.8	927.8
Net benefit (NB)	454.2	508.9	435.4	313.0
Benefit-cost ratio (BCR)	5.1	3.4	1.2	0.5
Profit index (PI)	113.6	10.2	2.9	1.7
Incidence cost (IC)	0.004	0.042	0.149	0.247

[1] 1 Euro = 655.95 FCFA; [2] Stocking usually through natural inundation; [3] Feed cost (FCFA/kg): Control = 1.1; T1 = 12.6; T2 = 46.6; T3 = 80.6;[4] Maintenance includes clearing of macrophytes and removing of pond bottom mud;[5] based on the price of 431 FCFA of one kilogram fresh unprocessed *Clarias* on-site

However, gross return increased with an increasing biomass production and was highest for treatment 3 followed by treatment 2. But, net benefit (NB) was best for treatment 1, whereas the control diet showed the best benefit-cost ratio (BCR) and also the lowest incidence cost (IC).

Tab. 13: Benefit-cost analysis for *C. gariepinus* reared with different experimental diets in 2008 (Evaluation based on the stocking density of 2 tons/ha)

Components / Treatments	Control diet	Treatment 1	Treatment 2	Treatment 3
Expenditures (x 1000 FCFA[1]; per ha)				
Fixed costs:				
'Whedo' preparation	20	20	20	20
Fingerling costs [2]	-	-	-	-
Feed cost [3]	7.2	97.2	409.1	765.6
Variable costs:				
Harvest and Maintenance [4]	30	30	30	30
Feeding costs	33.75	33.75	33.75	33.75
Total expenditures (TE)	91.0	181.0	492.9	849.4
Income (x 1000 FCFA[1]; per ha)				
Biomass harvested (kg)	1894.5	2301.8	2733.0	3106.9
Gross return [5] (GR)	816.5	992.1	1177.9	1339.1
Net benefit (NB)	725.6	811.1	685.1	489.7
Benefit-cost ratio (BCR)	8.0	4.5	1.4	0.6
Profit index (PI)	113.4	10.2	2.9	1.7
Incidence cost (IC)	0.004	0.042	0.150	0.246

[1] 1 Euro = 655.95 FCFA
[2] Stocking usually through natural inundation
[3] Feed cost (FCFA/kg): Control = 1.1; T1 = 12.6; T2 = 46.6; T3 = 80.6.
[4] Maintenance includes clearing of macrophytes and removing of pond bottom mud
[5] based on the price of 431 FCFA of one kilogram fresh unprocessed *Clarias* on-site

Gross return increased with increasing stocking density and thus an initial stocking of 2 tons per hectare resulted in higher gross returns. However, the economic indicators showed the same trend with the highest NB for treatment 1 and the best BCR and Incidence costs for the control group.

4.3.2 FEEDING TRIAL 2009

Feed Quality

The compositions of the different experimental diets are given in Table 14. Diets were not prepared to be isonitrogenous or isoenergetic since the study attempted to test whether or not the higher protein content of the diets, meaning the use of high quality feed ingredients, will lead to higher growth rates and if the higher productivity might cover the additional expenses of the diet. Treatment 2 showed the highest protein content (19.8 %) followed by treatment 1 with 14.7 percent. The control diet and treatment 3 showed the lowest protein level with 4.9 percent and 7.2 percent, respectively.

The crude ash content was highest for the treatment 3 (47.9 %) which was a consequence of the high proportion of bones in the incorporated fish trash.

Treatment 1 and 2 had an ash content of 20.8 percent and 22.9 percent, respectively. The higher ash content of the control diet compared to treatment 1 and 2 was the result of the high ash content of the rice bran. Because of the high inclusion rate of rice bran, the ash content was generally high in all treatments.

Table 14: Proximate composition of the experimental feeds
(expressed as percentage of dry matter or MJ/kg) and their local prices (FCFA/kg) in 2009.

Ingredients / Diets	Dry Matter	Crude Protein	Crude Fat	Ash	Gross Energy (MJ/kg)	Price (FCFA*/kg)
		as % of Dry Matter				
Control	93.3	4.9	5.4	26.5	15.0	1.1
Treatment 1	92.8	14.7	3.8	20.8	16.2	12.6
Treatment 2	93.0	19.8	3.6	22.9	16.1	22.9
Treatment 3	95.0	7.2	4.4	47.9	10.4	696.6

*1€ = 655.96 FCFA

The crude fat content was highest for the control diet. The lower crude lipid concentration of treatment 1 and 2 (3.8 % and 3.6 %, respectively) was the result of the low lipid content of the blood meal. Treatment 3 had a lipid content of 4.4 percent.

Gross energy was highest in treatment 1 followed by treatment 2 and the control, whereas treatment 3 had the lowest gross energy content.

Feed Intake and Behaviour of fish

Fish were fed for a total of 20 weeks. Fish belonging to the control group, treatment 1 and treatment 2, actively consumed the experimental feeds throughout the whole period of time meaning no negative effects were derived from the experimental diets. However, in treatment 3 fish stopped feeding actively after 2 weeks which was probably the consequence of the low palatability of the *azolla* meal.

Mortality was highest in treatment 3 (6.3 %) but did not differ significantly from all other treatments (Table 15). Survival rate was highest (94.9 %) in the group fed with the diet 2.

Growth Performance and Nutrient Utilization

The weekly growth performance and nutrient utilisation of the experimental diets are shown in Table 15 and Figure 4, respectively.

The body weight gain (BWG) in grams for the control and treatment 3 did not differ, but they were both significantly lower than for treatment 1 and 2. However, the highest BWG was achieved with the treatment 2 which was significantly higher than the BWG for treatment 1. Raw data of bi-weekly body weight gain are summarized in Appendix 3b.

The percentage body weight gain differed significantly among all treatments with treatment 2 showing the highest BWG, while the control diet showed the lowest growth performance.

The amount of feed offered (FO) did not differ between the control diet and treatment 3 and also not between treatment 1 and treatment 2. But the total feed offered during the experiment differed significantly ($P < 0.05$) between the control diet and treatment 2 as well as between treatment 1 and 3.

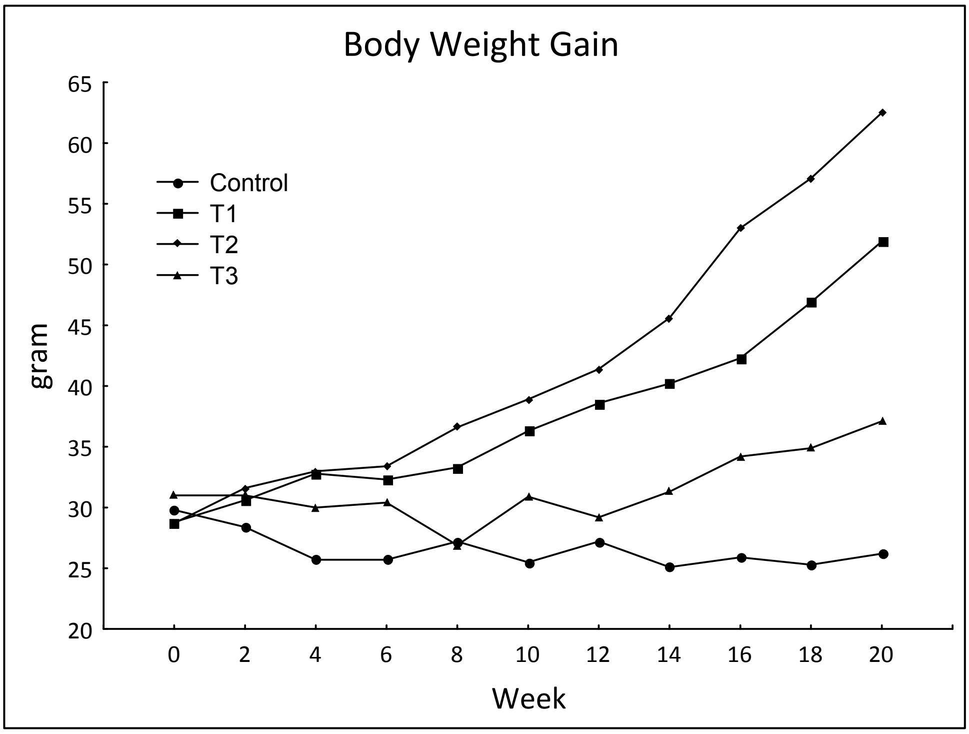


Figure 4: Weekly growth performance of *C. gariepinus* fed different experimental diets.

Protein efficiency ratio (PER) was highest in treatment 2 but did not show significant differences to treatment 1 and treatment 3. The control diet resulted in the lowest PER and showed significant differences to all other treatments.

Table 15: The growth performance and nutrient utilization of *C. gariepinus* feed different experimental diets

	Control	Treatment 1	Treatment 2	Treatment 3
IBW (g)	29.8^{a} ± 2.1	28.8^{a} ± 3.0	28.7^{a} ± 1.0	31.0^{a} ± 1.8
FBW (g)	26.2^{a} ± 0.6	51.2^{b} ± 9.5	62.5^{b} ± 8.5	37.1^{a} ± 4.3
BWG (g)	-3.53^{a} ± 1.92	22.48^{b} ± 7.38	33.85^{c} ± 7.56	6.19^{a} ± 2.78
BWG (%)	-11.6^{a} ± 5.48	77.8^{b} ± 21.16	117.7^{c} ± 22.18	19.8^{d} ± 8.19
SGR (%/d)	-0.10^{a} ± 0.05	0.48^{b} ± 0.10	0.65^{c} ± 0.08	0.15^{d} ± 0.06
FCE	-0.02^{a} ± 0.01	0.10^{b} ± 0.02	0.14^{c} ± 0.02	0.03^{d} ± 0.01
PER	-0.45^{a} ± 0.24	0.69^{b} ± 0.16	0.71^{b} ± 0.10	0.46^{b} ± 0.18
FO (g)	159.6^{a} ± 5.1	217.2^{bc} ± 22	239.5^{b} ± 20.5	185.9^{ac} ± 14.1
Mortality (%)	5.9^{a} ± 3.5	5.1^{a} ± 3.5	5.9^{a} ± 3.5	6.3^{a} ± 0.0
Survival rate (%)	94.1^{a} ± 3.5	94.9^{a} ± 3.5	94.1^{a} ± 3.5	93.7^{a} ± 0.0

IBW = initial body weight; FBW = final body weight; BWG = body weight gain; SGR = specific growth rate; FCE = feed conversion efficiency; PER = protein efficiency ratio; FO = feed offered. Different superscripts accentuate that they are significant differences between the diets (P < 0.05).

Specific growth rate (SGR) differed significantly among all the treatments showing the best result for treatment 2, whereas the lowest could be observed in the group fed with the control diet (Fig. 5).

Feed conversion efficiency differed significantly among all treatments. Lowest FCE was obtained by feeding the control diet followed by treatment 3, while treatment 2 showed the highest FCE (Fig. 5).

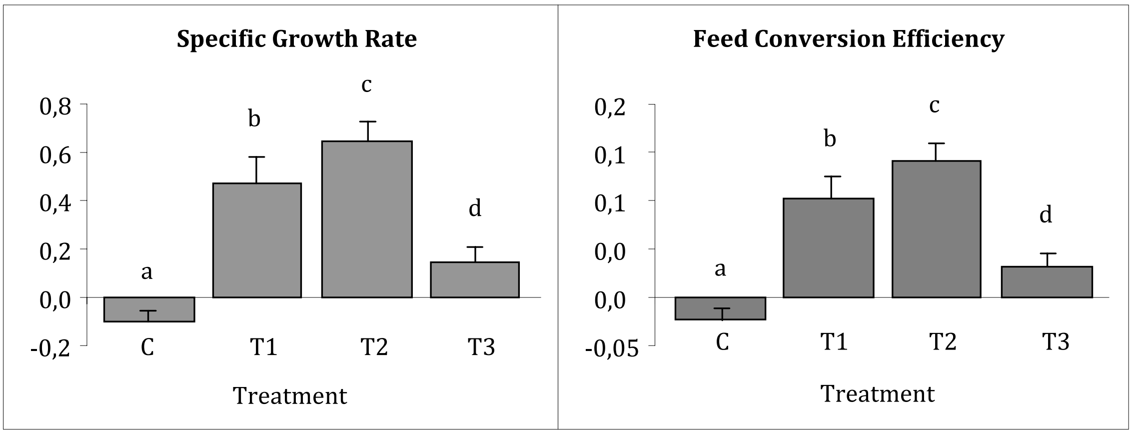


Fig. 5: Specific growth rate and feed conversion efficiency of *C. gariepinus* fed different experimental diets. Different superscripts accentuate that there are significant differences between the diets (P < 0.05).

Economic Evaluation

Table 16 shows the results of the experiment with a stocking density of 5 *Clarias*/m^2 extrapolated to one hectare, whereas in table 17 results are given for a stocking density of 2 tons/ha, which was the average biomass harvested in the 'Whedos' investigated in 2008 (HAUBER *et al.* 2011a).

Tab. 16: Benefit-cost analysis for *C. gariepinus* reared with different experimental diets in 2009 (Evaluation based on the stocking density of 5 *Clarias*/m² and on a hectare basis)

Components / Treatment	Control diet	Treatment 1	Treatment 2	Treatment 3
Expenditures (x 1000 FCFA[1]; per ha)				
Fixed costs:				
'Whedo' preparation	20	20	20	20
Fingerling costs [2]	-	-	-	-
Feed cost [3]	9.4	147.2	297.3	6981.0
Variable costs:				
Harvest and Maintenance [4]	30	30	30	30
Feeding costs	33.75	33.75	33.75	33.75
Total expenditures (TE)	93.2	231.0	381.0	7064.7
Income (x 1000 FCFA[1]; per ha)				
Biomass harvested (kg)	1240.5	2440.5	2956.6	1745.1
Gross return [5] (GR)	534.6	1051.8	1274.3	752.1
Net benefit (NB)	441.5	820.9	893.3	-6312.6
Benefit-cost ratio (BCR)	4.7	3.6	2.3	-0.9
Profit index (PI)	56.8	7.1	4.3	0.1
Incidence cost (IC)	0.01	0.06	0.10	4.0

[1] 1 Euro = 655.95 FCFA
[2] Stocking usually through natural inundation
[3] Feed cost (FCFA/kg): Control = 1.1; T1 = 12.6; T2 = 22.9 T3 = 696.6.
[4] Maintenance includes clearing of macrophytes and removing of pond bottom mud
[5] based on the price of 431 FCFA of one kilogram fresh unprocessed *Clarias* on site

Net profit was directly related to the type of experimental feed and total expenditure increased from the control diet containing solely rice bran to treatment 3 containing fish trash and *azolla* meal.

Tab. 17: Benefit-cost analysis for *C. gariepinus* reared with different experimental diets in 2009 (Evaluation based on the stocking density of 2 tons/ha)

Components / Treatment	Control diet	Treatment 1	Treatment 2	Treatment 3
Expenditures (x 1000 FCFA[1]; per ha)				
Fixed costs:				
'Whedo' preparation	20	20	20	20
Fingerling costs [2]	-	-	-	-
Feed cost [3]	12.6	204.3	413.3	8986.8
Variable costs:				
Harvest and Maintenance [4]	30	30	30	30
Feeding costs	33.75	33.75	33.75	33.75
Total expenditures (TE)	96.4	288.0	497.1	9070.6
Income (x 1000 FCFA[1]; per ha)				
Biomass harvested (kg)	1665.1	3366.0	4088.1	2244.1
Gross return [5] (GR)	717.7	1450.8	1762.0	967.2
Net benefit (NB)	621.3	1162.7	1264.9	-8103.4
Benefit-cost ratio (BCR)	6.4	4.0	2.5	-0.9
Profit index (PI)	56.8	7.1	4.3	0.1
Incidence cost (IC)	0.01	0.06	0.10	4.0

[1] 1 Euro = 655.95 FCFA; [2] Stocking usually through natural inundation; [3] Feed cost (FCFA/kg): Control = 1.1; T1 = 12.6; T2 = 22.9 T3 = 696.6; [4] Maintenance includes clearing of macrophytes and removing of pond bottom mud; [5] based on the price of 431 FCFA of one kilogram fresh unprocessed *Clarias* on site.

Gross return increased with an increasing biomass harvested and was highest for treatment 2 followed by treatment 1. Net benefit (NB) was best for treatment 2 whereas the control diet showed the best benefit-cost ratio (BCR) and also the lowest incidence costs (IC). Treatment 3 showed the lowest returns and proved to be not profitable.

An initial stocking of 2 tons per hectare resulted in higher gross returns. However, the economic indicators showed the same trend with the highest NB for treatment 2 and the best BCR and IC for the control group.

4.3.3 Feeding Trial 2008 and 2009 in Comparison

In order to be able to compare the feeding trial of 2008 with the experiment conducted in 2009, the growth parameters obtained in 2009 were re-calculated for a period of 10 weeks to match the duration of the experiment in 2008. In the following section the results will be presented. In comparing both experiments the different treatments were termed as follow:

Year 2008:

- Control feed	C/08
- Treatment 1 (10% Blood meal)	1/08
- Treatment 2 (10% Blood meal + 10% Groundnut cake)	2/08
- Treatment 3 (10% Blood meal + 20% Groundnut cake)	3/08

Year 2009:

- Control feed	C/09
- Treatment 1 (10% Blood meal)	1/09
- Treatment 2 (19% Blood meal)	2/09
- Treatment 3 (30% Fish Trash + 20% *Azolla* meal)	3/09

Growth Performance and Nutrient Utilization

The weekly growth performance and nutrient utilisation of all experimental diets applied in 2008 and 2009 are shown in Table 18 and Figure 6, respectively.

The body weight gain (BWG) in grams and as percentage did not result in significant differences between the control diets (C/08 and C/09) and also not between the experimental diets containing a ration of 10 percent of BM (T1/08 and T1/09). However, BWG was highest for treatment 3/08 followed by 2/08. But diet 2/08 did not show significant differences to the treatment 2/09. The control diets and the treatments 1/08 and 3/09 did also not differ significantly. Although, T3/09 showed a loss of weight (grams) from the onset of week 4, it did not differ from the control diets and T1 in 2008 and 2009.

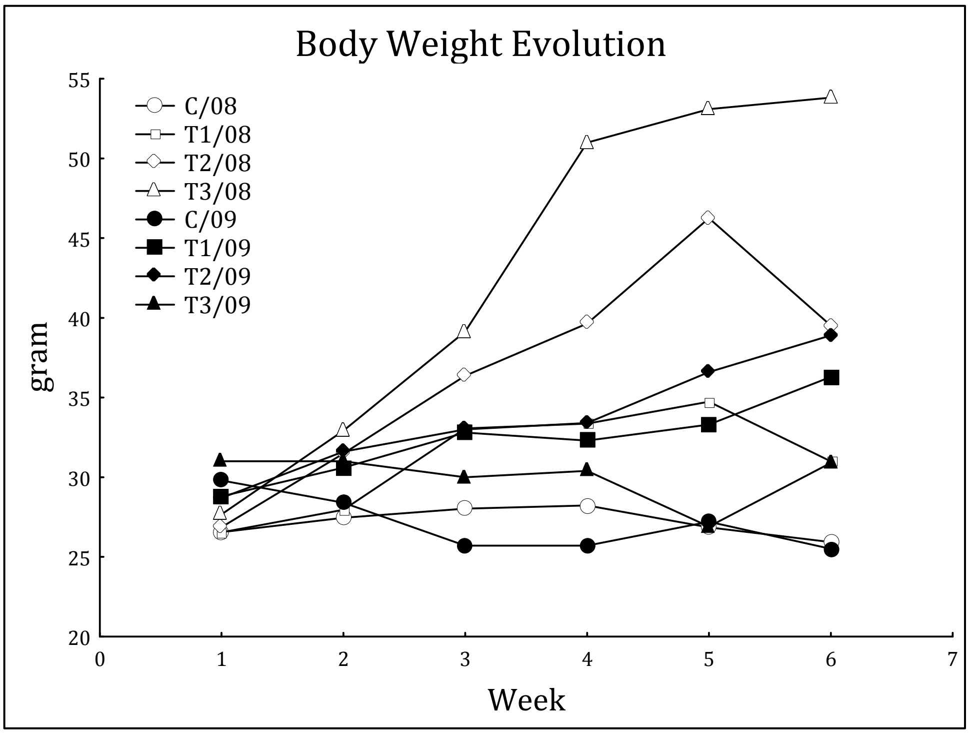


Figure 6: Weekly body weight gain of *C gariepinus* fed different experimental diets.

The amount of feed offered (FO) did not differ between the control diets, the treatment 1/08 and 3/09. However, treatment 3/08 consisted of the highest amount of feed offered followed by treatment 2/08. However, the amount of FO did not differ significantly between the treatments 2/08 and 2/09 (Tab. 18).

Protein efficiency ratio (PER) was highest in treatment 3/08 but did not result in significant differences to treatment 2/08. The control diet C/09 was significant lower than all other treatments. For the control diet in 2008 and treatment 3/09 the PER was in the same range as it was also for treatment 1/08 and treatment 1/09 (Tab. 18).

Specific growth rate (SGR) did also not differ significantly between the control diets and treatment 3/09. Also the two diets containing 10 percent of blood meal (1/08 and 1/09) did not result in significantly different SGR. Besides, SGR did not differ between treatments 1/09 and 2/09 and also not between treatments 2/08 and 2/09. Treatment 3/08 resulted in the highest SGR followed by treatment 2/08 (Fig. 7).

Table 18: The growth performance and nutrient utilization of *C. gariepinus* fed different experimental diets

Treatment	**C/08**	**T1/08**	**T2/08**	**T3/08**	**C/09**	**T1/09**	**T2/09**	**T3/09**
Growth		***2008***					***2009***	
BWG (g)	$-0.6^{ab}\pm 0.7$	$4.5^{b}\pm4.0$	$12.7^{c}\pm1.6$	$26.1^{e}\pm4.8$	$-4.2^{a}\pm1.6$	$7.5^{bc}\pm1.5$	$10.2^{c}\pm2.6$	$-0.04^{ab}\pm3.6$
BWG (%)	$-2.4^{ab}\pm2.6$	$16.9^{bc}\pm16$	$47.1^{d}\pm5.6$	$94.7^{e}\pm18.9$	$-14.1^{a}\pm5.0$	$26.7^{c}\pm8.1$	$35.7^{cd}\pm9.7$	$-0.3^{ab}\pm11.4$
SGR (%/d)	$-0.04^{a}\pm0.04$	$0.3^{b}\pm0.2$	$0.6^{d}\pm0.06$	$1.1^{e}\pm0.16$	$-0.3^{a}\pm0.1$	$0.4^{bc}\pm0.1$	$0.5^{cd}\pm0.1$	$-0.01^{a}\pm0.2$
FCE	$-0.01^{a}\pm0.01$	$0.05^{b}\pm0.05$	$0.1^{c}\pm0.02$	$0.2^{d}\pm0.02$	$-0.05^{a}\pm0.02$	$0.08^{bc}\pm0.02$	$0.1^{c}\pm0.03$	$0.0^{a}\pm0.04$
PER	$-0.2^{a}\pm0.2$	$0.4^{bc}\pm0.4$	$0.7^{c}\pm0.1$	$1.1^{c}\pm0.1$	$-1.04^{d}\pm0.4$	$0.6^{be}\pm0.1$	$0.5^{be}\pm0.1$	$-0.01^{ae}\pm0.6$
FO	$82.3^{a}\pm2.7$	$93.4^{ab}\pm9.0$	$108.4^{c}\pm6.9$	$122.3^{d}\pm10.7$	$82.1^{a}\pm3.6$	$94.6^{be}\pm7.5$	$97.9^{bce}\pm3.0$	$89.6^{ae}\pm2.9$

BWG = body weight gain; SGR = specific growth rate; FCE = feed conversion efficiency; PER = protein efficiency ratio; FO = feed offered. Different superscripts accentuate that there are significant differences between the diets ($P < 0.05$).

Feed conversion efficiency (FCE) did not differ significantly among the control diets and the treatment 3/09 containing fish trash and *azolla* meal. Also the two diets containing 10 percent of blood meal (1/08 and 1/09) did not result in significant different FCE. Highest FCE could be recorded in the group fed with treatment 3/08 followed by treatment 2/08 and 2/09. The treatments 2/08 and 2/09 were not significantly different (Fig. 7).

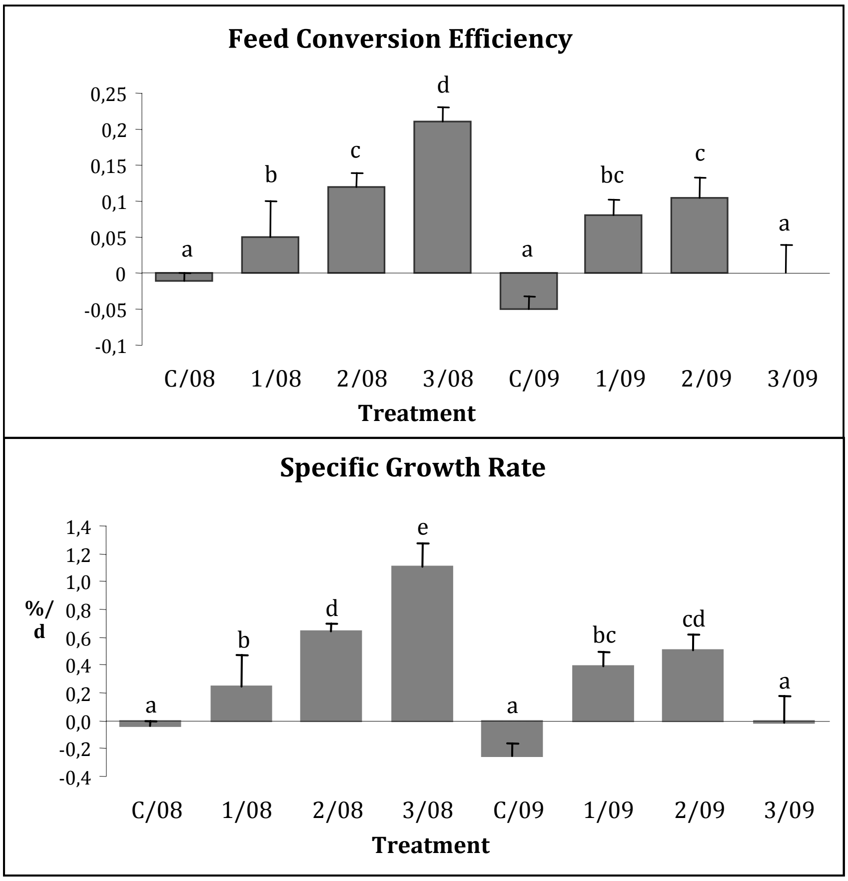


Fig. 7: Specific growth rate and feed conversion efficiency of *C. gariepinus* fed different experimental diets. Different superscripts accentuate that they are significant differences between the diets ($P < 0.05$).

Economic Evaluation

Table 19 and 20 summarize the economic analyses of the experiments in 2008 and 2009. Economic analyses were calculated for the stocking density of 5 *Clarias*/m^2 and on a hectare basis as well as for an initial stocking density of 2 tons/ha because this reflects the average stocking density of the local 'Tschifi dais' in 2008. The results for 2009 were given for an experimental period of 10 weeks in order to be able to compare them with the results obtained in 2008.

Tab. 19: Benefit-cost analysis for *C. gariepinus* reared with different experimental diets in 2008 and 2009 for 10 weeks. (Evaluation based on the stocking density of 5 *Clarias*/m² and on a hectare basis)

Components / Treatment	C/08	T1/08	T2/08	T3/08	C/09	T1/09	T2/09	T3/09
Expenditures (x 1000 FCFA¹; per ha)								
Fixed costs:								
'Whedo' preparation	20	20	20	20	20	20	20	20
Fingerling costs ²	-	-	-	-	-	-	-	-
Feed cost ³	4.8	64.6	275.7	531.1	4.9	64.2	121.8	3368.4
Variable costs:								
Harvest and Maintenance ⁴	30	30	30	30	30	30	30	30
Feeding costs	33.75	33.75	33.75	33.75	33.75	33.75	33.75	33.75
Total expenditures (TE)	88.5	148.4	359.4	614.9	88.6	148.0	205.5	3452.2
Income (x 1000 FCFA¹; per ha)								
Biomass harvested (kg)	1259.3	1525.1	1844.1	2152.7	1207.4	1728.4	1838.2	1452.2
Gross return ⁵ (GR)	542.8	657.3	794.8	927.8	520.4	745.0	792.3	625.9
Net benefit (NB)	454.2	508.9	435.4	313.0	431.8	597.0	586.7	-2826.3
Benefit-cost ratio (BCR)	5.1	3.4	1.2	0.5	4.9	4.0	2.9	-0.8
Profit index (PI)	113.6	10.2	2.9	1.7	107.2	11.6	6.5	0.2
Incidence cost (IC)	0.004	0.042	0.15	0.25	0.004	0.04	0.07	2.3

¹ 1 Euro = 655.95 FCFA; ² Stocking usually through natural inundation,³ Feed cost (FCFA/kg): C/08 = 1.1; T1/08 = 12.6; T2/08 = 46.6; T3/08= 80.6.; C/09 = 1.1; T1/09 = 12.6; T2/09 = 22.9 ; T3 /09 = 696.6. ⁴ Maintenance includes clearing of macrophytes and removing of pond bottom mud. ⁵ based on the price of 431 FCFA of one kilogram fresh unprocessed *Clarias* on site

The gross return was directly related to the total biomass harvested and thus was highest for the treatment T3/08 followed by T2/09. The control groups gave the lowest biomass production at the end of the experiment and therefore also the lowest GR.

Tab. 20: Benefit-cost analysis for *Clarias* reared with different experimental diets in 2008 and 2009 (Evaluation based on the stocking density of 2 tons/ha)

Components / Treatment	C/08	T1/08	T2/08	T3/08	C/09	T1/09	T2/09	T3/09
Expenditures (x 1000 FCFA¹; per ha)								
Fixed costs:								
'Whedo' preparation	20	20	20	20	20	20	20	20
Fingerling costs ²	-	-	-	-	-	-	-	-
Feed cost ³	7.2	97.2	409.1	765.6	6.5	89.2	169.5	4344.1
Variable costs:								
Harvest and Maintenance ⁴	30	30	30	30	30	30	30	30
Feeding costs	33.75	33.75	33.75	33.75	33.75	33.75	33.75	33.75
Total expenditures (TE)	91.0	181.0	492.9	849.4	90.3	173.0	253.2	4427.8
Income (x 1000 FCFA¹; per ha)								
Biomass harvested (kg)	1894.5	2301.8	2733.0	3106.9	1707.4	2517.7	2696.3	1982.9
Gross return ⁵ (GR)	816.5	992.1	1177.9	1339.1	735.9	1085.1	1162.1	854.6
Net benefit (NB)	725.6	811.1	685.1	489.7	645.6	912.2	908.9	-3573.2
Benefit-cost ration (BCR)	8.0	4.5	1.4	0.6	7.2	5.3	3.6	-0.8
Profit index (PI)	113.4	10.2	2.9	1.7	113.0	12.2	6.9	0.2
Incidence cost (IC)	0.004	0.042	0.15	0.25	0.004	0.04	0.07	2.2

¹ 1 Euro = 655.95 FCFA; ² Stocking usually through natural inundation; ³ Feed cost (FCFA/kg): C/08 = 1.1; T1/08 = 12.6; T2/08 = 46.6; T3/08= 80.6.; C/09 = 1.1; T1/09 = 12.6; T2/09 = 22.9; T3 /09 = 696.6; ⁴ Maintenance includes clearing of macrophytes and removing of pond bottom mud; ⁵ based on the price of 431 FCFA of one kilogram fresh unprocessed *Clarias* on site

But with regard to economic indicators such as the benefit-cost ratio, the profit index and the incidence cost, the control feed showed the best results in comparison to the other treatments.

In both experiments the treatments with a ration of 10 percent of blood meal (T1/08 and T1/09) resulted in the highest net benefit, whereas the treatment T3/09 containing fish trash and *azolla* meal showed a high economic loss which was expressed in the negative BCR as well as NB.

4.4. DISCUSSION

Additional income for the farmers could possibly be obtained by supplementary feeding of the fish. Though various feeding trials have been attempted, most of them were conducted under optimal conditions in laboratory facilities not considering natural circumstances such as unfavourable water quality. Studies under field conditions are rare and experimental diets are often formulated by using feed ingredients, *e.g.* fish meal and palm oil, which are not appropriate for application in rural areas. Therefore, prior to the study, on-site investigations were conducted focusing on the local markets and the processing sector to locate materials, together with their prices and availabilities, appropriate as potential supplementary feed for *C. gariepinus*. Based on these analyses five different materials (rice bran, blood meal, groundnut cake meal, fish trash and *azolla* meal) were chosen for the experiments.

In the course of the present study a significant decline of the alkalinity of the pond water even reaching concentrations under the minimum level of 20 mg/L $CaCO_3$ recommended for most aquaculture species (WURTS 2011) could be observed. But the alkalinity loss is not likely to be the consequence of biogenic decalcification since pH values did not increase significantly, but it might be the result of nitrification processes. The low values of ammonium (0.8 mg/L) encourage this assumption. The values for nitrate ranged from 3 to 6 mg/L in the morning. Nitrite concentrations varied between 0 and 0.2 mg/L and thus are comparable to the concentration of 0.03 to 0.15 mg/L recorded by TOKO *et al.* (2007) in 'Whedos' in the Ouémé Delta.

Dissolved oxygen concentrations were low and ranged from 0.9 to 1.2 mg/L corresponding to the measurements of TOKO *et al.* (2007). Low DO concentrations are characteristic for many TDs in the region and probably represent the crucial factor determining the seasonal fish diversity. As a consequence, highly adapted and air-breathing fish, particularly *Clarias* spp., are the common fish species dwelling the TDs (HAUBER *et al.* 2011b).

However, generally water quality parameters were in the tolerance range for *C. gariepinus* (VIVEEN *et al.* 1985; YONG-SULEM 2006; FROESE & PAULI 2010) and its suitability was also reflected in the relatively low mortality rates. But the groups fed with the diets containing a ration of 20 percent of groundnut press cake meal showed relatively low survival rates (79.5 %) compared to the other groups. Although the ground cake meal was stored under dry conditions the development of fungi was observed at the bottom of the bin leading to the assumption, although spores were not analysed, that the GPC meal was probably contaminated by aflatoxins. These are highly toxic mycotoxins produced by many species of A*spergillus* and well known to evoke serious fish mortalities (JANSSEN 1985; JAUNCEY 1998; JANTRAROTRAI & LOVELL 1991).

Actually, mortality rates in the control diets were expected to be higher compared with the other treatments since a considerable degree of cannibalism is known for *C. gariepinus* increasing particularly with inadequate food availability (AL-HAFEDH & ALI 2003; HECHT & APPELBAUM 1988; FOX 1975; POLIS 1981). But although fish fed solely on rice bran showed a significant weight loss as a consequence of insufficient feed supply mortality was not different compared to the other treatments.

However, the rice bran used contained a considerable amount of husks and thus a high proportion of fibre (LITI *et al.* 2006). High fibre content has been reported to reduce growth and to contribute to poor feed utilization since it is believed that fish lack effective cellulase activity that are necessary to digest cellulose (LEARY & LOVELL 1975). Considering the control groups (both in 2008 and 2009) growth parameters (SGR and BWG) showed negative performances, whereas these indicators improved significantly with a decreasing proportion of rice bran in the diets. Thus, it can be concluded that rice bran did not have direct nutritional benefit for *C. gariepinus* fingerlings (LITI *et al.* 2006).

Furthermore, in earthen ponds, such as the TDs, growth rates are also influenced by the natural food supply. Since fish fed the control diet showed stagnant or even negative growth rates it can be assumed that natural feed supply of the TDs was insufficient and did not contribute to significant growth, meaning that the fish were highly dependent on the supplementary feed. This leads to the assumption that the annual biomass harvested by the locals at the end of the dry season probably correspond with the biomass that is naturally stocked by flooding, meaning that fish trapped in the TDs do not gain weight during the four to five months of the growing cycle as a consequence of the insufficient feed supply.

With regard to the different experimental diets the results showed that final biomass and growth rates are positively related to the crude protein content of the diet (DEGANI *et al.* 1989), thus the treatments T3/08 and T2/09 showed the best growth performance at the end of the experimental period. But, although T3/08 and T2/09 possessed the same protein content (19.9 % and 19.8 %, respectively), the diet containing groundnut cake together with blood meal showed a significantly better growth performance (SGR, BWG, FCE and PER) than the diet containing blood meal as only source of protein. However, despite the extremely high protein content of the blood meal (91.7 % to 94.2 %), it only has a low biological value because of its minor levels of isoleucine, methionine and arginine, whereas GPC meal contains high levels of arginine and also sufficient amounts of isoleucine (HARRIS 1980; GUILLAUME & METAILLER 2001; JAUNCEY 1998). Therefore, the combination of blood meal with GPC meal probably helped to enrich the experimental diet. OTUBUSIN (1987) who studied different inclusion levels of blood meal (10 %, 25 % and 50 %) in diets for *Oreochromis niloticus* reported that a ration of 10 percent of blood meal was the most effective in terms of average weight gain as well as average final fish weight and concluded as well that the amino acid profile of blood meal has a low nutritional value.

Nevertheless, the growth performances obtained in the present studies figure well in the range of those reported in the literature (EGWUI 1986; DEGANI *et al.* 1989; FAGBENRO & AROWOSOGE 1991; FAGBENRO 1992; POUOMOGNE 1995; AKEGBEJO-SAMSON 2008) although protein content tested by the different authors was significantly higher than in our studies. For example AKEGBEJO-SAMSON (2008) only obtained a specific growth rate of 0.89 by feeding a diet containing a considerable amount of blood meal and a protein level of 40 % to *Clarias* fingerlings compared to the SGR of 1.1 obtained in our study by feeding the diet T3/08 with a comparatively poor protein content of 19.9 percent. POUOMOGNE (1995) fed a mixture of 80 percent of rice bran and 20 percent of groundnut cake meal with a protein level of 20.3 percent and obtained a SGR of 0.6 which is comparable with the SGR of 0.64 and 0.51 obtained in our study by feeding the diets T2/08 (16.7 % CP) and T2/09 (19.8 % CP), but did not reach the growth rate of the diet T3/08 although protein content was nearly the same.

By feeding household wastes with an protein content of 37 percent to *Clarias* fingerlings FAGBENRO & AROWOSOGE (1991) obtained relatively poor SGR ranging from 0.27 to 0.41. However, the protein efficiency ratio of 1.69 to 2.54 was better than the PER of only 0.4 to 1.1 obtained in our studies, which might be again the consequence of the low biological value of the blood meal. Best PER was obtained in the group fed the diet with the highest content of groundnut press cake (T3/09) and thus showed again the compensation of the amino acid inbalance of blood meal by supplementing groundnut cake meal. However, EGWUI (1986) who fed a protein-rich mixture of fish feed pellets, groundnut- and palm kernel cake in the ratio 1:1:1 obtained PER between 1.0 and 1.5, and SGR ranging between 0.39 and 0.59. These values are comparable with the results obtained in the present studies; although we did not use such high qualitative feed ingredients.

By comparing the specific growth rate of the control diets and the treatments containing 10 percent of blood meal (T1/08 and T2/09), it can be observed that they differed, although not significantly, between the two experimental periods of 2008 and 2009. For the diets T1/08 and T1/09, the higher SGR in 2009 might probably be the result of the higher protein content (14.7 % versus 12.6 %) deriving from the higher protein concentration of the blood meal used for the formulation. But, the protein level cannot be the reason for the lower weight loss of fish fed with the control diet in 2008, since crude protein content was higher in 2009 (4.9 % and 4.4 %, respectively). But the higher ash content of the rice bran fed in 2009 might be one reason for the poor feed utilization.

Furthermore, the diet T3/09 containing fish trash and *azolla* meal resulted in poor growth performance and did not significantly differ from the control diets. One reason leading to the poor growth performance might be an unpalability of *azolla* meal for *C. gariepinus* since fish refused to feed actively on the diet after only two weeks. In addition, as a consequence of the sterilisation process and the associated protein degradation, the crude protein content of the unprocessed fish trash decreased significantly from 53 to 21.1 percent; probably resulting in a loss of its nutritive value and an overall low protein level of the diet (7.2 %).

In general, the use of fish trash is not recommended because the economic indicators of its application, such as net income and benefit-cost ratio, were negative (Table 19 and 20). Although, fish trash is free in the market, its processing (drying, grinding and sieving) is very labour intensive resulting in elevated costs per kilogram of dry fish meal. Furthermore, also the feasibility of the drying process is questionable since the smell of the fish attracted a lot of insects and thus it needs adequate preventive measures to guarante hygienical production conditions and this would lead once more to additional costs.

As already mentioned biomass production increased with increasing protein content of the diet; thus resulting in higher gross returns but consequently also in higher total feed cost (Tab. 19 and 20). Although, the treatments T2/08 and T3/08 (mixture of groundnut cake and blood meal) achieved the highest biomass production, net benefit and benefit-cost ratio was higher in the treatments T1/08, T1/09 and T2/9 with blood meal as single protein source. Surprisingly, even the profit and the different cost-benefit calculations obtained by feeding only rice bran (average values of 2008 and 2009; Tab. 21) achieved higher economic benefits than the diets based on groundnut cake meal. However, with regard to T3/09, the total cost of feed could not be compensated by additional biomass production; therefore leading to high economical losses.

Since the economic benefit obtained by feeding the diets containing 10 percent of blood meal (T1/08 and T1/09) differed between 2008 and 2009, we used the mean value (Table 21) to be able to compare the economic indicator with those obtained by feeding the diet containing 19 percent of blood meal (T2/09). The results showed that diet T2/09 resulted in a higher net benefit on a hectare basis, as well as with an initial stocking density of 2 tons/ha, than the diet containing only 10 percent of blood meal.

However, apart from the results discussed above, comparable economic indicators for 2008 and 2009 are based on the result obtained after 10 weeks of feeding and extrapolated to one hectare or 2 tons per hectare, respectively. But, usually the growing cycle lasts the whole dry season, from the end of November to the end of April, thus fish have considerably more time to grow-out and to reach higher final body weight. The results obtained after the feeding period of 20 weeks already showed a significant higher economic benefit (Tab. 16 and 17). Regarding the diet T2/09 containing 19 percent blood meal, the net benefit on a hectare basis could be increased to 820,900 FCFA (1251 €) compared to only 441,500 FCFA (673 €) with the control diet.

Additionally, since local fish prices are dependent on the sizes of fish, total income of the TD owners will increase with increasing final fish weight. For example in 2008 and 2009, one kilogram of small *Clarias* earned 431 FCFA/kg (0.66 €), whereas purchase prices increased to 536 FCFA (0.82 €) for one kilogram of medium sized fish (average of 350g). Bigger fish were sold individually and one *Clarias* of 1.2 kg can earn approximately 1,000 FCFA (1.53 €).

Tab. 21: Average benefit-cost analysis for the control and the diets containing 10 % blood meal fed in 2008 and 2009. (Evaluation based on the stocking density of 5 *Clarias*/m² on a hectare basis and based on the stocking density of 2tons per hectare).

Treatment / **Components**	**Average Control**	**Average of T1**	**Average Control**	**Average of T1**
	one hectare		*2 tons/ha*	
Expenditures (x 1000 FCFA; per ha)*				
'Whedo' preparation	20	20	20	20
Fingerling costs *				
Feed cost *	4,8	64,4	6,9	93,2
Variable costs:				
Harvest and Maintenance *	30	30	30	30
Feeding costs	33,75	33,75	33,75	33,75
Total expenditures (TE)	88,6	148,2	90,6	177,0
Income (x 1000 FCFA; per ha)*				
Biomass harvested (kg)	1233	1627	1801	2410
Gross return* (GR)	531,6	701,1	776,2	1038,6
Net benefit (NB)	443,0	553,0	685,6	861,7
Benefit-cost ratio (BCR)	5,0	3,7	7,6	4,9
Profit index (PI)	110,4	10,9	113,2	11,1
Incidence cost (IC)	0,004	0,040	0,004	0,039

[1] 1 Euro = 655.95 FCFA
[2] Stocking usually through natural inundation
[3] Feed cost (FCFA/kg): C/08 = 1.1; T1/08 = 12.6; C/09 = 1.1; T1/09 = 12.6;
[4] Maintenance includes clearing of macrophytes and removing of pond bottom mud
[5] based on the price of 431 FCFA of one kilogram fresh unprocessed *Clarias* on site

Moreover, real net benefit might also be higher because of a higher natural stocking density of 2 tons per hectare (Table 20), representing the average biomass harvested by the locals in 2008. Since fish did not gain any weight in the control groups it can be concluded that the final biomass harvest at the end of the dry season corresponded to the biomass stocked through the annual flooding of the rivers.

Additionally, total expenditures will decrease because since 2009, two governmental projects are focusing on the development of the 'Whedo'-aquaculture-system by supporting further 'Whedo' constructions. They are providing 50,000 FCFA for each newly constructed 'Tschifi dai' to the owners, with the precondition that they will dig at least five of them.

4.5 CONCLUSION

Because of high demographic growth and the overexploitation of the rivers in the densely populated region of Malanville, it is important to find sustainable alternatives to increase fish supply. In the town of Malanville, consumers in the local fish market are complaining about the diminishing supply of fish deriving from the traditional river fishery, thus the consumption of imported chilled fish increased from 16,630 kg in 1999 to 33,000 kg in 2007 (unpublished data of the local fishery department).

Recent estimations assume that since 1998 approximately 500 TDs with an average dimension of 200 m^2 (HAUBER *et al.* 2011b) have been constructed in the environment of Malanville forming a total surface area of approximately 10 ha. Therefore, the potential biomass production can reach up to 20,000 kg without supplementary feeding and biomass production could even be improved by feeding the fish regularly, thus contributing to an improved fish supply in the region.

The results obtained in the studies showed that:

- Fish naturally stocked in the TDs by the annual flooding event did not gain weight in the course of the growing cycle because of inadequate natural food availability.
- Supplementary feed of high quality such as groundnut press cake is economically not profitable because the additional feed costs cannot be compensated by the higher biomass since local fish prices are too low. Moreover, the risk of high fish mortalities caused by a contamination with aflatoxin is too high.
- The use of fish trash as supplementary feed is not recommendable because its processing is too labour intensive leading to disproportional high production costs and additionally created serious hygienic problems.
- Blood meal showed the best results with regard to the economic benefits and thus has a high potential as an inexpensive, effective and locally available protein supplement in diets for *C. gariepinus* fingerlings.

Generally, fish farming in TDs is an attractive system for the rural population because of existing knowledge of post-flood wetland fisheries, as well as the low investment cost needed for its installation. Natural stocking also reduces the cost of purchasing fingerlings and solves other procurement problems but it is important to increase the recognition amongst the owners that additional feeding with inexpensive supplementary feed material will enhance their annual biomass yields, thus improving their additional income significantly.

Furthermore, it might be worthwhile to install a small-scale feed mill to be able to prepare different supplementary feeds on an economic scale leading to a regular and cheaper supply of fish feed. It might also be beneficial for the biomass production to lime the 'Whedos' regularly since alkalinity which is an important factor for the natural productivity of ponds is under the recommended level of 20 mg/L $CaCO_3$ (WURTS 2011).

4.6. LITERATURE

ABOU, Y., FIOGBE, E.D. & MICHA, J.-C. 2007. Effects of stocking density on growth yield and profitability of farming Nile Tilapia. *Oreochromis niloticus* L., fed Azolla diet, in earthen ponds.

ADCP - Aquaculture Development and Co-ordination Programme 1983. Fish feeds and feeding in developing countries. An interim report on the ADCP feed development programme. FAO-ADCP/REP/83/18. Rome, Italy. p. 97.

AHOYO, H-C. 2005. Impact des activités humaines sur la conservation des zones humides du Nord-Bénin: Cas des Affluents Alibori et Sota du Fleuve Niger; Mémoire de Fin d'études. Université Abomey-Calavi. FSA – UAC; Benin.

AKEGBEJO-SAMSON, Y. 2008. Use of rendered animal protein meals as fish meal replacement in diets of the African Catfish, *Clarias gariepinus* (Burchell, 1822) Juveniles. *Tropicultura* 26 (2): 89-92.

AL HAFEDH, Y.S. 1999. Effects of dietary protein on growth and body composition of Nile tilapia, Oreochromis niloticus L. *Aquac. Res.* 30: 385-393.

ANETEKHAI, M.A., AKIN-ORIOLA, G.A., ADERINOLA, O.J . &AKINTOLA, S.L. 2004. Steps ahead for aquaculture development in Sub-Saharan Africa - the case of Nigeria. *Aquaculture* 239: 237-248.

AOAC 1990. Official methods of analysis, 15th edn. Association of Official Analytical Chemists. Arlington. V. A.

BRUMMETT, R.E. & WILLIAMS, M.J. 2000. The evolution of aquaculture in African rural and economic development. *Ecological Economics* 33: 193-200.

BRUTON, M.N. 1979a. The food and feeding behaviour of *Clarias gariepinus* (Pisces; Clariidae) in Lake Sibaya, South Africa, with emphasis on its role as a predator of cichlids. *Trans. Zool. Soc. London.* 35: 47-114.

BRUTON, M.N. 1979b. The breeding biology and early development of *Clarias gariepinus* (Pisces; Clariidae) in Lake Sibaya, South Africa, with a review of breeding in the subgenus *Clarias (Clarias). Trans. Zool. Soc. London.* 35: 1 – 45.

BRUTON, M.N. 1988. Systematic and Biology of Clariid Catfish. Pp. 1-11 *In* HECHT, T., UYS, W. & BRITZ, P.J. (eds.). The culture of sharp tooth catfish, *Clarias gariepinus* in southern Africa. South African National Scientific Programmes report No. 153. p. 133.

BURGESS, W.E. 1989. An atlas of freshwater and marine catfishes. A preliminary survey of the Siluriformes. T.F.H. Publications, Inc., Neptune City, New Jersey (USA). p. 784.

CHONG, K.C. 1993. Economics of on-farm aquafeed preparation and use. Pp. 148-160 *In* NEW, M.B., TACON, A.G.J. & CSAVAS, I. 1994. Farm-made Aquafeeds. Proceedings of the FAO/AADCP Regional Expert Consultation on farm-made Aquafeeds, 14-18 Dec. 1992. FAO- RAPA/AADCP. Fisheries Bangkok, Thailand. p. 434.

DAGET, J. 1959. Les poisons de Niger supérieur. Bull. IFAN XXI, Série A, No.2. p. 676.

DAGNELIE, P. 1975. Théorie et Méthodes Statistiques. Vol. II., Presses Agronomiques de Gembloux. Belgique. p. 463.

DEGANI, G., BEN-ZVI, Y. & LEVANON, D. 1989. The effect of different protein levels and temperatures on feed utilization, growth and body composition of *Clarias gariepinus* (Burchell 1822). *Aquaculture* 76: 293-301.

DE GRAAF, G. & JANSSEN, J. 1996. Handbook on the artificial reproduction and pond rearing of the african catfish *Clarias gariepinus* in sub-sahara Africa. Fisheries Technical Paper 362. FAO, Rom.

DE MOOR, I.J. & BRUTON, M.N. 1988: Atlas of alien and translocated indigenous aquatic animals in southern Africa. A report of the Committee for Nature Conservation Research National Programme for Ecosystem Research. South African Scientific Programmes Report No. 144. Port Elizabeth, South Africa. p. 310.

DE SILVA, S.S. 1993. Supplementary feeding in semi-intensive aquaculture systems. Pp. 24-60 *In* NEW, M.B., TACON, A.G.J. & CSAVAS, I., 1994. Farm-made Aquafeeds. Proceedings of the FAO/AADCP Regional Expert Consultation on farm-made Aquafeeds, 14-18 Dec. 1992. FAO- RAPA/AADCP. Fisheries Bangkok, Thailand. p. 434.

DUNCAN., D.B. 1955. Multiple range and multiple tests. *Biometrics* 11: 1-42.

ECCLES, D.H. 1992. FAO species identification sheets for fishery purposes. Field guide to the freshwater fishes of Tanzania. Prepared and published with the support of the United Nations Development Programme (project URT/87/016). FAO, Rome. p. 145. http://fishbase.de/photos/PicturesSummary.php?StartRow=11&ID=1934&what=species&TotRec=14. Accessed January 2011.

EGWUI, P.C. 1986. Yields of the African catfish, *Clarias gariepinus* (Burchell), from a low input, homestead, concrete pond. *Aquaculture* 55: 87-91.

EL BOLOCK, A.R. 1969. Catfish Culture. FAO Fish Culture Bulletin 2 (1): 7.

FAGBENRO, O.A. & AROWOSOGE, I.A. 1991. Replacement value of some household wastes as energy substitutes in low-cost diets for rearing catfish in South-Western Nigeria. *Bioresour. Technol.* 37: 197-203.

FAGBENRO, O.A. 1992. Utilization of cocoa-pod husk in low-cost diets by the clariid catfish *Clarias-isheriensis* Sydenham. *Aquaculture and Fisheries Management* 23: 175-182.

FERRARIS, Carl J., Jr. 2007. Checklist of catfishes, recent and fossil (Osteichthyes: Siluriformes), and catalogue of siluriform primary types. *Zootaxa* 1418: 1–628. http://silurus.acnatsci.org/ACSI/library/biblios/2007_Ferraris_Catfish_Checklist.pdf. Accessed December 2010.

FRANCIS, G. 2001. Antinutritional factors present in plant-derived alternate fish feed ingredients and their effects in fish. *Aquaculture* 199: 197-227.

FROESE, R. & PAULY, D. 2010. FishBase, World Wide Web electronic publication. www.fishbase.org. Assessed November 2010.

FOX, L.R. 1975. Cannibalism in natural populations. *Ann. Rev. Ecol. Syst*. 6: 87-106.

GIETEMA, B. (ed.) 1999. Fish Farming in tropical freshwater ponds - Book 1. Foundation for the Development of Agricultural Education and Training. STOAS.Wageningen, the Netherlands.

GROENEWALD, A.A. 1964. Observation on the food habits of *Clarias gariepinus* (Burchell), the South Africa freshwater barbell in Transvaal. *Hydrobiologia* 23: 287-291.

GUILLAUME, J. & METAILLER., R. 2001. Antinutritional Factors. Pp. 297-307 *In* GUILLAUME. J., KAUSHIK. S., BERGOT, P. & METAILLER R. (eds.). Nutrition and Feeding of Fish and Crustaceans. Springer-Praxis Book Aquaculture and Fisheries. MPG Books Ltd. Bodmin, Cornwall, UK. p. 411.

HALVER, J. E. 1989. Fish nutrition (2nd Edition). Academic Press. p. 798.

HARRIS, L.E. 1980. Feedstuffs. Pp. 111-170 *In* PILLAR T.V.R. (ed). Fish Technology, Lectures presented at the FAO/UNDP Training course in Fish Feed Technology, College of Fisheries, 9 October – 15 December, 1978. University of Washington, Seattle, WA.

HAUBER, M.E., BIERBACH, D. & LINSENMAIR, K.E.L. 2011a. The Traditional Whedo Aquaculture System in Northern Benin. *Journal of Applied Aquaculture* 23 (1): 67-84.

HAUBER, M.E., BIERBACH, D. & LINSENMAIR, K.E.L. 2011b. A description of teleost fish diversity in floodplain pools ('Whedos') and the Middle-Niger at Malanville (north-eastern Benin). *Journal of Applied Ichthyology* 27: 1-5.

HECHT, T. & APPELBAUM, S. 1988. Observations on intraspecific aggression and coeval sibling cannibalism by larval and juvenile *Clarias gariepinus* (Clariidae, Pisces) under controlled conditions. *J. Zool.* 214: 21-44.

HECHT, T., OELLERMANN, L. & VERHEUST, L. 1996. Perspectives on clariid catfish culture in Africa. *Journal of Aquatic Living Resources* 9: 197-206.

HELFMAN, G. S. 2007. Fish conservation. A guide to understanding and restoring global aquatic biodiversity and fisheries resources. Island Press, Washington.

HEPHER, B. 1988. Nutrition of Pond fishes. Cambridge University Press. p. 388.

JACKSON, A.J., CAPPER, B.S. & MATTY, A.J. 1982. Evaluation of some plant proteins in complete diets for the tilapia *Sarotherodon mossambicus*. *Aquaculture* 27: 97-109.

JACKSON, P.B.N., 1988: Aquaculture in Africa. Pp. 459-480 *In* LÉVÊQUE, C., BRUTON, M.N. & SSENTONGO G.W. (eds). Biology and Ecology of African Freshwater Fishes. Edition de l'ORSTOM, Paris. p. 509.

JANSSEN, J. 1985. Elevage du poisson-chat africain *Clarias lazera* (Cuv & Val., 1840), Part IV – Alimentation. FAO Technical Paper N° 23. Project GCP/CAF/007/NET. FAO, Bangui.

JANTRAROTAI, W. & JANTRAROTAI, P. 1993. On-farm feed preparation and feedings strategies for catfish and snakehead. Pp. 101-119 *In* NEW, M.B., TACON A.G.J. & CSAVAS, I. (eds.). Farm-made aquafeeds. Processing of the FAO/AADCP Regional Expert Consultation on Farm-Made Aquafeeds. 14-18 December 1992. FAO-RAPA/AADCP. Bangkok, Thailand. p. 434.

JANTRAROTRAI W. & LOVELL R.T. 1991. Subchronic toxicity of aflotoxin to B1 channel catfish. *J. Aquat. Anim. Health* 2: 248-254.

JAUNCEY, K. 1998. Tilapia feeds and feeding. Institute of Aquaculture of Stirling, Scotland. Benfoy Press Ltd. p 241.

KARANTH, S. & SELVARAJ, S. 2005. African Catfish: A potential candidate species for urban/periurban aquaculture in India. *Aquaculture* 10: 11-12.

KUMAR, D. 1992. Fish Culture in Undrainable Ponds. FAO Fisheries Technical Paper Nº 325. FAO, Rom.

LALEYE, P., AKELE, D. & PHILIPPART, J.C. 2007. La pêche traditionnelle dans les plaines inondables du fleuve Ouémé au Bénin. *Cahier d'Ethologie* 22 (2): 25-38.

LAUZANNE, L. 1988. Les habitats alimentaires des poissons d'eau douce africains. Pp. 221-234 *In* LÉVEQUE, C., BRUTON, M.N. & SSENTONGO, G.W. Biology and Ecology of African Freshwater Fishes. ORSTOM Edition, Paris.

LEGENDRE, M. & LEVEQUE, C. 2006. l'aquaculture. Pp. 457-471 *In* LEVEQUE, C. & PAUGNY D. (eds.). Les poisons des eaux continentales africaines. IRD, Paris.

LEVEQUE C. 2006: Les introductions d'espèces. Pp. 381-395 *In* LEVEQUE, C. & PAUGNY D. (eds.). Les poisons des eaux continentales africaines. IRD, Paris. p. 564.

LEARY, D.F. & LOVELL, R.T. 1975. Value of fiber in production-type diets for channel catfish. Transactions of the American Fisheries Society 104: 328-332.

LITI, D.M., MUGO, R.M., MUNGUTI, J.M. & WAIDBACHER, H. 2006. Growth and economic performance of Nile tilapia (*Oreochromis niloticus* L.) fed on three brans (maize, wheat and rice) in fertilized ponds. *Aquaculture Nutrition* 12: 239-245.

LITTLE, D. & MUIR, J. 1987. Integrated Warm Water Aquaculture, Institute of Aquaculture. University of Stirling, Scotland. p. 238.

MACHIELS, M.A.M. & HENKEN, A.M. 1985. Growth rate, feed utilization and energy metabolism of the African catfish *Clarias gariepinus* (Burchell, 1822), as affected by dietary protein and energy content. *Aquaculture* 44: 271-284.

MAKKAR, H.P.S. 1993. Antinutritional factors in foods for livestock. Pp. 69-85 *In* GILL, M., OWEN, E., POLLOT, G.E. & LAWRENCE, T.L.J. (eds.). Animal Production in Developing Countries. Occasional publication No. 16. British Society of Animal Production.

MICHA, J.C. 1973. Etude des populations piscicoles de l'Ubangui et tentative de sélection et d'adaptation de quelques espèces à l'étang de pisciculture. Centre Technique Forestière Tropical, Nogent sur Marne. p. 100.

MORITZ, T., LALEYE, P., KOBA, G. & LINSENMAIR, K.E. 2006. An annotated list of fish from the River Niger at Malanville, Benin, with notes on the local fisheries. *Verhandlung der Gesellschaft für Ichthyologie* 5: 95-110.

MOUSSA, T.A. 1957. Physiology of the accessory respiratory organs of the teleost, *Clarias lazera*. *J. Exp. Zool.* 136: 419-454.

MUNRO, J.L. 1967. The food of a community of East African freshwater fishes. *J. Zool.,* Lond. 151: 389-415.

MWEBAZA-NDAWULA, L. 1984. Food and feeding habits of *Clarias mossambicus*; from four areas in the Lake Victoria basin, East Africa. *Environmental Biology of Fishes* 10: 69-76.

NAEGEL, L.C.A. 1997. Azolla meal as supplementary feed ingredients for tilapias. Pp. 20-30 *In* Fitzimmons, K. (ed.). Proc. 4th Intl. Symp. on Tilapia in Aquaculture, 9-11 November 1997. Orlando. FL, USA.

NEW, M.B., TACON, A.G.J. & CSAVAS, I. 1994. Farm-made Aquafeeds. Fisheries Technical Papers 343. FAO, Rom.

NYINA-WAMWIZA, L., WATHELET, B. & KESTEMONT, P. 2007. Potential of local agricultural by-products for the rearing of african catfish in Rwanda-effects on growth, feed utilization and body composition. *Aquatic. Research* 38: 206-214.

OKEYO, D.O. 2003. On the biodiversity and the distribution of freshwater fish of Namibia: an annotated update. Pp. 156-194 *In* PALOMARES, M.L.D., SAMB, B., DIOUF, T., VAKILY, J.M. & PAULY, D. (eds.). Fish biodiversity: local studies as basis for global inferences. ACP-EU Fish. Res. Rep. 14. p. 281.

OLIVERA-NOVA, M.A., CAMPUS, G., SAPIDO & MARTINEZ-PALACOIS, G.M. 1990. the use of alfalfa leaf protein concentrates as a protein source in diets for Tilapia (*Oreochromis mossambicus*). *Aquaculture* 90: 291-302.

OTUBUSIN, S.O. 1987. Effects of different levels of blood meal in pelleted feeds on Tilapia, *Oreochromis niloticus*, production in floating bamboo net-cages. *Aquaculture* 65: 263-266.

POLIS, G.A. 1981 The evolution and dynamics of intra-specific predation. *Ann. Rev. Ecol. Syst.* 12: 225-251.

POUOMOGNE, V. 1995. Comparison du son du riz et du tourteau d'arachide pour la croissance des juveniles du poisson-chat africain *Clarias gariepinus. Aquat. Living Resour.* 8: 403-406.

PRODECOM 2006. Schéma directeur d'aménagement de la commune de Malanville: analyse et diagnostic. SERHAUS-SA. Cotonou-Bénin. p. 23.

SHAPIRO, S. S., WILK, M. B. & CHEN, H. J. 1968. A comparative study of various tests of normality. *Journal of the American Statistical Association* 63: 1343-1372.

SIEGEL, S., and CASTELLAN, N.J. 1988. Nonparametric statistics for the behavioural sciences (2nd ed.) New York: McGraw-Hill.

SMEDES, F. 1999. Determination of total lipid using non-chlorinated solvents. *Analyst* 124: 1711-1718.

STICKNEY, R., CASTELL, J., HARDY, R., KETOLA, R., LOVELL, R. & WILSON, R. 1983: Nutrient Requirements of Warmwater Fishes and Shellfishes. National Academic Press, Washington D.C. p. 103.

TEUGELS, G.G. 1982a. Preliminary results of a morphological study of five nominal species of the subgenus *Clarias* (Pisces; Clariidae). *Journal of Natural History* 16 (3): 439-464.

TEUGELS, G.G. 1982b. Preliminary data of a systematic outline of the African species of the genus *Clarias* (Pisces; Clariidae). *Revue de zoologie africaine,* 96 (4): 731-748.

TEUGELS, G.G. 1984. The nomenclature of African *Clarias* species used in aquaculture. *Aquaculture* 38: 373-374.

TEUGELS, G.G. 1986. A systematic revision of the African species of the genus *Clarias* (Pisces; Clariidae). *Ann. Mus. r. Afr. cent., Sci. Zool.,* 247. p. 199.

TEUGELS, G.G. & GOURÈNE, G. 1998. Biodiversity and aquaculture of African catfishes (teleostei, Siluroidei): an overview. Pp. 229-239 *In* J.F. AGNÈSE (ed.). Genetics and Aquaculture in Africa. ORSTOM Edition, Paris. p. 327.

TOKO, I., FIOGBE, E.D., KOUKPODE, B. & KESTMONT, P. 2007. Rearing of African catfish (*Clarias gariepinus*) and vundu catfish (*Heterobranchus longifilis*) in traditional fish ponds (whedos): Effect of stocking density on growth, production and body composition. *Aquaculture* 262: 65-72.

UYS, W. 1989. Aspects of the nutritional physiology and dietary requirements of juvenile and adult sharptooth catfish, *Clarias gariepinus* (Pisces: Clariidae). PhD Thesis, Rhodes University Grahamstown, South Africa. p. 190.

VAN WEERD, J.H. 1995. Nutrition and growth in *Clarias* species – a review. *Journal of Aquatic Living resources* 8: 395-401.

VIVEEN, W.J.A.R., RICHTER, C.J.J., VAN OORDT, P.G.W.J., JANSEN, J.A.L. & HUISMAN, E.A. 1985. Manuel pratique de pisciculture du poisson-chat Africain (*Clarias gariepinus*). The Netherlands Ministry for Development Cooperation, Section for Research and Technology, P.O. Box 20061, 2500 EB The Hague, The Netherlands. p. 128.

WELCOMME, R.L. & DE MERONA, B. 1988. Fish communities of rivers – Peuplements ichtyologiques des rivières. Pp. 251-276 *In* LEVEQUE, C. BRUTON M. & SSENTONGO G. (eds.). Biologie et écologie des poisons d'eau douce africains. ORSTOM, 216. Paris, France. p. 509.

WELCOMME, R. L., BRUMMETT, R. E., DENNY, P., HASAN, M. R., KAGGWA, R. C., KIPKEMBOI, J., MATTSON, N. S., SUGUNAN, V. V. & VASS, K. K. 2006. Water Management and Wise Use of Wetlands: Enhancing Productivity. Pp. 155-180 *In* VERHOEVEN, J. T. A., BELTMAN, B., BOBBINK R. & WHIGHAM D. F. (eds.). Wetlands and Natural Resource Management Springer Berlin Heidelberg.

WITTE, F. & DE WINTER, W. 1995. Appendix II. Biology of the major fish species of Lake Victoria. Pp. 301-320 *In* WITTE, F. & VAN DENSEN W.L.T. (eds.). Fish stocks and fisheries of Lake Victoria. A handbook for field observations. Samara Publishing Limited, Dyfed, Great Britain.

WORTHINGTON, E.B. & RICARDO, C.K. 1936. *Linnean Society's J. Zool.* 39 (267). p. 372.

WURTS, W.A. 2011. Alkalinity and hardness in production ponds. Kentucky State University CEP at UK Research and Education Center.
www.ca.uky.edu/wkrec/Wurtspage.htm. Accessed March 2011.

YONG-SULEM, S., TCHANTCHOU, L., NGUEFACK, F. & BRUMMETT, R.E. 2006. Advanced nursery of *Clarias gariepinus* (Burchell. 1822) fingerlings in earthen ponds. through recycling of tilapia recruits. *Aquaculture* 256: 212-215.

GENERAL CONCLUSION & OUTLOOK

With regard to the strong demographic growth in Sub-Saharan Africa and the devastating state of the fishery, it does not seem reasonable to expect marine and inland capture fisheries of Africa to yield the growing demand for fish. Population growth of Malanville averaged 4.8 percent in the last decade resulting in an increasing demand for food, *e.g.* the consumption of chilled fish increased from 16,630 kg in 1999 to 33,000 kg in 2007 (unpublished data of the local fishery department). In order to be able to nourish this growing population in the future it is essential to find alternatives to enhance local food security in a sustainable way.

According to the consumers and fishmongers interviewed, in the last decade the supply of fish decreased significantly in quantity but also in regard to quality resulting in annually increasing market prices to the detriment of the poor. It seems only logical that contemporaneous farmers and fishermen start to trap migrating fish in so called 'Whedos' or 'Tschifi dais' constructed in the floodplain of the main rivers. Since the onset of this development in 1998, the number of 'Whedos' showed an important increase, and the financial assistance provided from the governmental projects PADPPA and PADFA operating since 2009 supported further constructions.

The 'Whedo'-aquaculture-system offers evident advantages. Thus it was quickly accepted by the indigenous population because of the already existing knowledge on post-flood wetland fisheries and the low investment needed for its installation. Failures of the system, as were reported from introduced aquaculture systems, are unlikely to happen because unlike modern aquaculture, traditional fisheries enhancement systems have evolved in the African social context without outside assistance and are based on local knowledge; thus the 'Whedo'-aquaculture-system is believed to be culturally and socially appropriate.

The potential of this traditional fishery enhancement system considering its future suitability and acceptance in other regions apart from West Africa is founded on one side on the assumption that their productivity can be improved through higher inputs such as fertilizer, fish feed or additional stocking and on the other side that this system can also be implemented in modified form in other African and even Asian countries, meaning that appropriate conditions for their development will also exist in many other regions. Even in areas without this kind of fishery enhancement system there are possibilities for installing the 'Whedo'-aquaculture-system through intra-regional transfer of the traditional knowledge and technology.

Nevertheless, the investigations showed clearly that the system is still in its infancy and there is still a lack of basic knowledge *e.g.* in regard to the choice of optimal sites and maintenance strategies guaranteeing best conditions for the breeding of the fish (see Chapter II Recommendations). Therefore, it is essential to provide the fish farmers with technical support in order to prevent frustrations and the abandonment of 'Whedos' caused by mismanagement

In this spirit, I organised a work shop in Malanville after the completion of the second feeding trial and field manuals in French and Dendi were written and handed over to the farmers for further distribution within the villages. For participation, from each of the villages investigated, two to three representatives were invited and trained in basic principles and furthermore they were given the opportunity to exchange their experiences with the other participants.

In this context, we also discussed the results obtained from the feeding trials explaining the fish farmers that supplementary feeding will enhance growth rates of the fish, resulting in higher biomass production. Hence, farmers were not only trained in the processing of the blood meal and the formulation of the diet, but also to be careful in the selection of appropriate feed materials since high quality feed might not be profitable as a result of the low local market price of fish.

Besides, although the diet containing the blood meal showed the best economical benefits, these results are based on the conditions that blood meal and rice bran were free of charge during the whole study period. But, a rising demand for those by-products could possibly (and will most probably) lead to a price demand which then changes the profitability, requiring a new economical evaluation to guarantee a net profit that justifies the additional costs and efforts required for the preparation and application of the supplementary feed.

However, fish traded on the regional market and in groceries in Malanville has to be registered by the fishery department. Although, it is unlikely that all traded fish was recorded, in 2007 the official consumption accounted 417,341 tons including fresh, smoked and chilled fish. Considering the potential biomass production of the 'Whedos' of 118 tons (calculated with the average biomass of 11.8 tons in 2008 and 2009 on a per hectare basis separately for each of the 'Whedos' and a water surface of 10 hectare), its contribution to the overall demand with 0.03 percent is very low highlighting the necessity and also opportunity to increase its market share.

One important contribution to the expansion of this 'Whedo'-aquaculture-system would be the provision of a catfish nursery to provide the farmers regularly with fingerlings appropriate for stocking in the 'Whedos'. Such a breeding nursery, financed by the government, is currently under construction in the town Malanville (Fig. 1).

Furthermore, the installation of a small local feed mill would guarantee a regular provision of supplementary feed and the higher quantity of feed produced might also lead to lower feed production prices. Besides, a local feed mill would on one site release farmers' work load and on the other side create some place of employment.

Fig. 1: Newly constructed catfish-nursery in Malanville

But despite the fast development and high potential of the system as alternative of enhancing local food security, further studies are essential to clarify whether an increased number of 'Whedos' might transform the nature of the floodplain in a way which will negatively affect its fish community and biodiversity.

SUMMARY

This work delves into the recently developed 'Whedo'-aquaculture-system in the rural community of Malanville (North Benin). 'Tschifi dais' or 'Whedos' are small artificial depressions (median and mode 200 m^2) that are dug within the floodplain during the dry season. Fish migrating into the inundation zone during the rainy season are trapped when the water recedes. These fish holes are thence isolated from the river during the dry season and some farmers are stocking their 'Whedos' additionally. In the last decade the study region experienced a kind of 'blue revolution' and since 1998 more than 464 of these fish holes were constructed without any financial support, thus highlighting their esteem by the indigenous population as well as the benefits received from their management.

However, this study aims on providing a closer insight on this – for the area--recent system including the ecological but also the sociological and economical aspects in order to develop this extensive traditional fishery to a more productive semi-intensive aquaculture system.

In the course of the study the characteristics of the 'Whedos' were analysed dividing them in three different categories:

1. 'Whedos' flooded directly by the overspill of rivers and local rain falls
2. 'Whedos' flooded indirectly through overflowing irrigation channels and rice fields
3. 'Whedos' only nourished through ground water and local rain.

With the retreat of the flood 'Whedos' usually become infested with numerous hydato- and tenagophytes, while the presence and density of the free-floating macrophytes were positively related to the nutrient content of the 'Whedo'. The general absence of submerged plants is a consequence of the high turbidity and the competition for light and space with the surface-floating plant species, thus resulting in a low photosynthetic activity meaning low dissolved oxygen concentrations. Extensive plant infestation also affects water quality through the decomposition of organic material and its accumulation in thick mud layers on the pond bottom as well as through the nocturnal oxygen consumption.

Most of the 'Whedos' have in common that water quality is deteriorating in the course of the dry season and 'Whedos' of the category 3 usually desiccate completely. Unfavourable water quality, especially low dissolved oxygen as well as high conductivity

and nitrite levels, was identified to be the main factor determining which fish species were able to survive the harsh conditions prevailing in the 'Whedos' during the dry season. In view to the 'Whedos' of the category 2, water quality, although not optimal, remains almost constant and thus species richness of those fish holes was generally quite low and did not show an important species loss in the course of the year.

However, with regard to the 'Whedos' of the category 1 results showed that species diversity at the time of the flood did not show significant differences compared to the main rivers and was generally higher than fish diversity recorded for category 2. But with the deteriorating water quality with advancing dry season, fish diversity decreased significantly and therefore was very similar to the species composition of the channel-flooded 'Whedos' leaving only species that are highly adapted to such unfavourable conditions. The most abundant species were *Clarias gariepinus*, *Heterotis niloticus*, *Oreochromis niloticus* L., *Hemichromis* c.f. *letourneauxi*, *Polypterus senegalus* and *Epiplatys spilargyreius.* But *Clarias* spp. was by far the most important species because it accounted for at least 90 percent of the total output (kg of total biomass harvested) in 10 out of the 16 investigated 'Whedos'; hence forming the major part of the income of the farmers. Additionally, interviews with the fishmongers and consumers made clear that *Clarias* is also the fish species mostly appreciated because of its nutritive boneless meat and the suitability to preserve it by smoking.

Besides, the investigations also concentrated on the fish diversity of the rivers Niger and Sota with the results that for three species distribution gaps could be closed and for further three species their already known distribution could be expanded. But otherwise it could also be detected that some economically important species that were abundant in the past, as *e.g. Parachanna obscura* and *Gymnarchus niloticus* have disappeared from the catches.

In regard to the 'Whedo'-management, the investigations showed that farmers and fishermen usually unite to form association of 22 members on average possessing an average of three 'Whedos'. But as a consequence of the missing technical support and also the short history of this system the owners lack most of the knowledge on appropriate management strategies, *e.g.* the feeding and stocking regime as well as the maintenance of the 'Whedos'.

The exploitation period usually depends on the extent of the previous annual flood and the location of the 'Whedo' within the floodplain, but the main season is from

February to April. Usually harvest is conducted in one day by dragging a seine net several times the length of the pond, but bigger or highly productive 'Whedos' may be harvested several times. The biomass harvested on a hectare basis separated for each of the 'Whedos' averaged 17 tons/ha in 2008 and 8.6 tons/ha in 2009, but when summarizing the total biomass harvested on the total water surface of the exploited 'Whedos', annual average yield was 3 t/ha in 2008 to 2.1 t/ha in 2009.

The harvested fish were usually sold directly on-site and the income was dependent on the size as well as the stocking density of the respective 'Whedo'. Realized gross income ranged between 68,758 (104.81 €) and 327,000 FCFA (498.5 €) not counting home consumption and donations to the workers or the village chief.

Although fish farming is a males' business, women are now integrated within this sector in marketing, processing and distribution of the fish. Before reselling mongers usually smoke or fry the fish, though some are transported alive in water for sale at their homestead.

However, 72 percent of the total biomass of *Clarias* only had an average weight of 40 grams thus showing that natural food supply is inadequate to support growth. Therefore, based on the information gathered from interviewing farmers, mongers and consumers as well as through personal participation and observation combined with detailed market analysis, two separated feeding trials were conducted. For this purpose 15 experimental 'Whedos' were constructed within the rice perimeter of Malanville and in total 6 supplementary feeds were tested on *Clarias gariepinus*. Groundnut press cake, fish trash, rice bran, blood meal and *azolla* meal were used in different combination and rations to formulate the experimental diets.

Results of the feed experiments showed that rice bran did not have any direct nutritional benefit for *C. gariepinus* fingerlings since growth rates stagnated or were even negative, while diets containing different rations of groundnut press cake meal (10 and 20 %) showed the best results with regard to the growth parameters. But the high costs of the groundnut press cake resulted in low net benefit and additionally its application always implies the risk of the contamination of the feed with toxic aflatoxins.

Moreover, the use of fish trash and *azolla* meal is not recommended. The economic indicators were all negative because processing was too labour-intensive, thus resulting in high production costs. Moreover, the poor growth performance of this supplementary feed might be a result of the unpalability of *azolla* leaf meal for *C. gariepinus.*

The diet containing 19 percent blood meal resulted in the best economical benefits showing that the use of high quality feed ingredients such as groundnut press cake is not recommendable because local fish prices are too low to compensate the additional feeding costs. Instead of high quality feed farmers should focus on ingredients that are free of charge and easy to process. The supplementation based on 19 percent blood meal resulted in the doubling of the net profit compared to the income based on feeding only rice bran, thus provided higher additional income, enhancing the livelihood of the fish farmers.

Concluding, the 'Whedo'-aquaculture-system is still in its infancy but nevertheless is an attractive system for the rural population because of existing knowledge of post-flood wetland fisheries *e.g*. fishing in marshes and natural depressions in the floodplain, as well as the low investment needed for its installation. Additionally, the local fish supply will increase and hence not only contribute to a better provision of protein-rich food and reduced pressure on the wild fish stocks but might also prevent fish prices to increase in a way that the poor won't be able anymore to afford their most important source of animal protein. But fish farmers need more knowledge on appropriate management strategies and thus should be provided with technical support to guarantee a successful development and not to discourage the owners as a consequence of avoidable failures. Furthermore, the use of supplementary feed offers a cheap and effective means to increase the biomass production and thus enhance the extensive fishery to a semi-intensive aquaculture system.

ZUSAMMENFASSUNG

Die vorliegende Arbeit befasst sich mit dem unlängst entwickeltem ‚Whedo'-System im ländlichen Bezirk Malanville (Nordbenin). ‚Whedos' sind im Überflutungsgebiet künstlich angelegte Vertiefungen/Fischlöcher (Median 200 m^2), die als Fischfallen fungieren. Viele Fische verbringen die Paarungs- und Leichzeit in den überfluteten Auenbereichen, bevor sie mit dem Eintritt der Ebbe wieder in die Flüsse zurückkehren. Mit dem Rückzug des Wassers und der abgeschnittenen Verbindung zum Fluss werden einige dieser Fische in den ‚Whedos' gefangen und am Ende der Trockenzeit von den Besitzern geerntet.

Das Untersuchungsgebiet erlebte im letzten Jahrzehnt eine Art ‚Blaue Revolution' und seit 1998 wurden mehr als 464 ‚Whedos' neu ausgehoben. Die Konstruktion der ‚Whedos' erfolgte ohne jegliche finanzielle Unterstützung, sondern wurde alleine von der Landbevölkerung bewerkstelligt und verdeutlicht somit die Akzeptanz seitens der einheimischen Bevölkerung und den Nutzen, den diese Entwicklung erbringt. Daher wurde die Arbeit darauf ausgerichtet, nähere Erkenntnisse über die Bewirtschaftungsweise der ‚Whedos' und deren jüngsten Entwicklungen in diesem Gebiet zu erlangen. Ein Einblick in die ökologischen, aber auch soziologischen and ökonomischen Aspekte ist die Grundlage für die Fortentwicklung dieser extensiven traditionellen Fischerei in eine ertragsreichere semi-intensive Fischzucht.

Im Rahmen dieser Recherche wurden die Eigenschaften der ‚Whedos' bezüglich der Art und Dauer der Überschwemmung untersucht und folglich in drei Kategorien unterteilt:

1. ‚Whedos', die mit dem Fluss in direkter Verbindung stehen
2. ‚Whedos', die nur indirekt mit dem Fluss verbunden sind und durch überlaufende Bewässerungskanäle und Reisfelder überschwemmt werden.
3. ‚Whedos', die nur durch Grund- und Regenwasser gespeist werden.

Mit dem Rückgang der Flut werden die Fischlöcher gewöhnlich von zahlreichen Hydato- und Tenagophyten überwuchert, wobei der Grad des Schwimmpflanzenbewuchses positiv mit dem Nährstoffgehalt des Wassers korrelierte. Das Fehlen von submersen Pflanzen beruhte auf der starken Wassertrübung und der Konkurrenz um Licht und Lebensraum mit den unterschiedlichen Schwimmpflanzenarten und zeigte sich folglich in einer geringen Photosyntheseleistung d.h. in geringen Saustoffkonzentrationen des Wassers. Außerdem wirkte sich der starke Pflanzenbewuchs, dadurch negativ auf die Wasserqualität aus, dass sich dicke Schichten abgestorbener Pflanzenmaterials auf dem Untergrund bildeten, die zu einer starken Sauerstoffzehrung führten.

Die meisten Fischlöcher zeigten eine, mit fortschreitender Regenzeit abnehmende Wasserqualität, wobei die ‚Whedos' der Kategorie 3 gewöhnlich komplett austrockneten. Schlechte Wasserqualität, vor allem geringe Sauerstoffkonzentrationen und hohe Salz- und Nitritgehalte, wurde als der bestimmende Faktor für das Vorkommen der Fischarten in den ‚Whedos' während der Trockenzeit identifiziert.

In den ‚Whedos' der Kategorie 2 blieb die Wasserqualität zwar suboptimal aber verschlechterte sich während der Trockenzeit nicht wesentlich. Dies erklärt die saisonunabhängige Fischdiversität in diesen ‚Fischlöchern'.

Bei den ‚Whedos' der Kategorie 1 zeigte sich, dass sich ihre Fischdiversität während der Überflutung nicht signifikant von der der Hauptflüsse unterschied. Aber generell wiesen sie einen höheren Artenreichtum als die ‚Whedos' der Kategorie 2 auf. Jedoch nahm die Fischdiversität mit zunehmender Verschlechterung der Wasserqualität signifikant ab und unterschied sich letztendlich in ihrem Artenreichtum nicht mehr von dem der ‚Whedos' der Kategorie 2, die nur noch Arten als Habitat dienten, die an schlechte Wasserqualität speziell angepasst sind.

Die häufigsten Arten waren *Clarias gariepinus*, *Heterotis niloticus*, *Oreochromis niloticus* L., *Hemichromis* c.f. *letourneauxi*, *Polypterus senegalus* und *Epiplatys spilargyreius.* Doch *Clarias* spp. war, mit einem Anteil von mindestens 90 Prozent an der Gesamternte (kg Biomasse) bei 10 von 16 befischten 'Whedos' die bei weitem - auch ökonomisch - bedeutendste Art. Auch Händler- und Konsumentenumfragen verdeutlichten, dass *Clarias* bei der lokalen Bevölkerung aufgrund seines schmackhaften, grätenarmen Fleisches und seiner Eignung zur Räucherung hoch geschätzt ist.

Zusätzlich beschäftigte sich diese Arbeit auch mit der Fischdiversität der Flüsse Niger und Sota. In diesem Rahmen wurden für drei Fischarten Verbreitunglücken geschlossen und für drei weitere Arten deren bereits bekanntes Verbreitungsgebiet erweitert. Im Gegensatz dazu konnte jedoch auch festgestellt werden, dass ehemals stark vertretende Fischarten, vor allem *Parachanna obscura* und *Gymnarchus niloticus*, aus den Fängen der Fischer verschwunden sind.

Die Studien zur Bewirtschaftungsweise der ‚Whedos' zeigten, dass sich die Bauern und Fischer gewöhnlich zu Gemeinschaften aus durchschnittlich 22 Mitgliedern vereinigen und im Durchschnitt drei Fischlöcher besitzen. Auf Grund der fehlenden technischen Unterstützung und auch der noch jungen Geschichte dieses Systems mangelt es den Besitzern an dem Wissen um die besten Managementstrategien. Dies gilt gleichermaßen für Fütterungs- und Besatzmaßnahmen als auch für die längerfristige Instandhaltung der Fischlöcher.

Der Zeitpunkt der Befischung hängt im Allgemeinen von der Flutintensität, der Lage des Fischloches innerhalb des Überflutungsgebietes und auch von den Marktpreisen ab, wobei die meisten Ernten zwischen Februar und April, kurz vor Beginn der nächsten Regenzeit im Mai, stattfanden.

Gewöhnlich wurde die Ernte an einem Tag, mit der Hilfe eines Zugnetzes, das mehrmals der Länge nach durch das Fischloch gezogen wird, durchgeführt. Größere oder ertragreiche ‚Whedos' werden aber auch über mehrere Tage hin, meistens in wöchentlichen Abständen, befischt.

Der durchschnittliche Biomasseertrag, basierend auf den Werten der einzelnen ‚Whedos' betrug 17 Tonnen im Jahre 2008 und 8,6 Tonnen im Jahre 2009; jedoch bei Umrechnung des gesamten Biomasseertrags auf die gesamte bewirtschaftete Wasserfläche erzielte die Ernte 2008 durchschnittlich 3 t/ha und 2009 rund 2,1 t/ha.

Die geernteten Fische wurden gewöhnlich direkt am Fischloch verkauft, wobei das Einkommen durch die Dimension und Besatzungsdichte der Fischlöcher bestimmt wurde. Ohne Einbezug des Eigenverbrauchs und der Abgaben an Erntehelfer und den Dorfchef lagen die Bruttoeinnahmen zwischen 68758 (104,81 €) und 327000 FCFA (498,5 €).

Obwohl die Fischzucht als reine Männersache angesehen wird, werden die Frauen durch ihre Tätigkeit in der Vermarktung, Verarbeitung und dem Vertrieb in den Sektor integriert. Vor der Veräußerung werden die Fische gewöhnlich geräuchert oder frittiert, manche werden jedoch lebend in Wasser gehalten und an der eigenen Wohnstätte verkauft.

Bei der Ernte sind die Fische im Mittel noch sehr klein. 72 Prozent der geernteten *Clarias* besaßen lediglich ein Durchschnittsgewicht von 40 g. Dies verdeutlicht das unzureichende natürliche Nahrungsangebotes der ‚Whedos', das für ein gutes Wachstum bei hoher Besatzdichte nicht ausreichend war.

Um die Wachstumsraten der Fische zu verbessern wurden zwei unterschiedliche Fütterungsversuche durchgeführt. Für diesen Zweck wurden 15 ‚Whedos' innerhalb der Reisanbaufläche von Malanville ausgehoben und insgesamt 6 verschiedene Futtermittel an *Clarias gariepinus* getestet. Die Versuchsplanung und die Wahl der Futtermaterialien basierten auf den Erkenntnissen, die anhand zahlreicher Umfragen, persönlicher Teilnahme und Beobachtungen sowie detaillierter Marktanalysen erlangt wurden. Erdnusspresskuchen, Fischabfälle, Reisspelzen, Blutmehl und *Azolla*-Mehl wurden in verschiedenen Zusammensetzungen und Anteilen als Grundlage der Futtermittel verwendet.

Die Versuchsergebnisse zeigten, dass Reisspelzen keinen direkten Nährwert für *Clarias* Jungfische besaßen, da die Wachstumsraten entweder stagnierten oder die Fische sogar an Gewicht verloren.

Die Futtermittel mit einem Anteil von 10 bzw. 20 Prozent Erdnusspresskuchen erzielten die höchsten Gewichtszunahmen. Jedoch führten die hohen Marktpreise des Presskuchens, dass von der Bevölkerung auch für die Zubereitung von Soßen verwendet wird, zu einem geringen Nettogewinn. Zusätzlich zu den hohen Produktionskosten birgt die Lagerung des Erdnussmehls auch die Gefahr einer Kontaminierung mit giftigen Schimmelpilzen (Aflatoxine).

Der Fütterung von Fischabfällen kombiniert mit *Azolla*-Mehl ist aufgrund der Versuchsergebnisse nicht empfehlenswert. Alle ökonomischen Indizes waren, als Folge der arbeitsintensiven Verarbeitung und der dadurch hohen Produktionskosten, negativ. Zudem zeigte sich, dass *Azolla*-Mehl für *Clarias* eine geringe Schmackhaftigkeit besitzt, da die Fische nach geraumer Zeit die aktive Nahrungsaufnahme einstellten.

Die Futtermittel mit einem Anteil von 10 bzw. 19 Prozent Blutmehl wurden von den Fischen während der gesamten Fütterungsperiode aktiv konsumiert und erzielten die höchsten Nettogewinne.

Die Versuchsergebnisse zeigen deutlich, dass qualitativ hochwertige Materialien nicht als Ergänzungsfutter geeignet sind, da die geringen Marktpreise für Fisch die zusätzlichen Kosten nicht decken können. Anstatt qualitativ hochwertigem Ergänzungsfutter sollten die Besitzer Materialien bevorzugen, die kostenlos bzw. günstig und zudem einfach zu verarbeiten sind.

Das Ergänzungsfutter mit einem Blutmehlgehalt von 19 Prozent erzielte, im Vergleich zur gewöhnlichen Fütterung mit Reisspelzen, einen zweimal höheren

Nettogewinn. Das zusätzlich erwirtschaftete Nebeneinkommen könnte somit zu einem verbesserten Lebensunterhalt der Besitzer beitragen.

Obwohl sich das ‚Whedo'-System noch in seinen Anfängen befindet, wird es von der ländlichen Bevölkerung aufgrund der bestehenden Erfahrungen mit der Befischung von Überflutungsgebieten und der geringen Installationskosten, hoch geschätzt und weiter ausgebaut.

Zudem führt die Bewirtschaftung der ‚Whedos' zu einem regional steigendem Angebot an Fisch und somit nicht nur zu einer verbesserten Nahrungsmittelversorgung und geringerer Befischungsintensität der natürlichen Bestände, sondern auch zu geringeren Preisanstiegen, die dazu führen könnten, dass die arme Bevölkerung nicht mehr in der Lage wäre ihre wichtigste tierische Proteinquelle zu erstehen.

Aber die Besitzer müssen technische Unterstützung und mehr Wissen über adäquate Managementstrategien erhalten, um eine zukünftig erfolgreiche Bewirtschaftung der ‚Whedos' zu garantieren und Enttäuschungen aufgrund vermeidbarer Fehler zu verhindern.

Außerdem, bietet der Einsatz eines Ergänzungsfuttermittels eine günstige und effektive Methode die Erträge der ‚Whedos' zu steigern und die extensive traditionelle Fischerei zu einer semi-intensivem Fischzucht auszubauen.

ACKNOWLEDGEMENTS/DANKSAGUNG

First of all I want to thank **Prof. K. E. Linsenmair**, who gave me the frame for this study. He made it possible to conduct my field work in Africa by giving me the big opportunity to become a member of the BIOTA-West Africa Project and therefore also warranted the financial support. Prof. Linsenmair did not only provide fruitful discussions considering my work but also supported me in a hard time and buoyed me up with his words of encouragement.

My sincerely thank goes furthermore to Dr. **Timo** Moritz. He was instrumental in my employment as well as the further introduction in my new field of activities. Furthermore, he provided me confidence and conveyed his expert knowledge not only to me but also to the diploma student David Bierbach.

Further I want to thank Assongba Danhin Yao **Norbert** (Fishery association of Malanville) for his own initiative in training and assisting the fish farmers and for his technical support and experience-based advices and help. Due to his engagement most useful contacts to farmers were tied and several of the ponds studied were located. Additionally we also spend some of long tropical evenings together and he introduced me to the Beninese culture and customs.

My gratitude goes especially to my diploma student **David** Bierbach with whom I spend a nice but also busy time in Benin. I hope he will forgive me that I forgot to pick him up at the airport, hence providing a good basis for our team work. Nevertheless, he exhibited a high motivation and carried out the identification of the fish species we worked with. In the frame of a further employment and with the collaboration and help of the Senkenberg Museum in Frankfurt, particularly with Dr. Marko Schmidt, he took also care for the identification of the different plant species. I am also thankful to **Maren** Rahmann for visualising all the single GPS points on a GIS map of the study area.

I also thank Prof. **Philippe** Lalèyè from the university Abomey-Calavi who provided me with fruitful discussions on my intention. Thanks also to **Simon** Montchou for helping me with the provision of an accommodation at the campus as well as Dr. **Antoine**

Chikou who accompanied me the long way to the far North to help me by the first but not last house-hunting.

In the field further people helped me with words and deeds:
My regard goes to the two dozen workers from Monkassa without them the construction of the 15 experimental ponds as well as their maintenance would never be possible. Moreover, I express my gratitude to Amidou Nourou-**Dine**, Bossou **Arouna**, **Bako Mourei**, **Meskine**, **Meagan** Hoff, **Kolé Kolé**, **Moussa** and **Nsidou** for their assistance and guiding to the different sites and **Monique** who acted as translator between me and the indigenous farmers just speaking the local language *Dendi*.

My big thank goes to Dr. **Hilary** Sydenham, who rescued my fingerlings and thus my whole project from the premature death. He provided some ponds for 2500 fish when they were shortly before asphyxia on the way from Porto-Novo to Malanville. In this sense I also want to thank Dr. **David** Cram from the 'Projet Piscicole de Parakou' who provided some more 3000 Clarias fingerlings in the following year, thus not only facilitating their supply and transport but also make it easier on my nerves. He further helped me a lot by proofreading of the thesis.

My thanks are also directed to **Prof. Dr. Klaus Becker** (University of Hohenheim) who was so kind to provide me his laboratory to analyse the feedstuff used within the different trial. In this time I highly appreciate the help and friendship of **Beatrix** Fischer and **Hermann** Baumgärtner.

Moreover, I am very indebted to **Dr. Ziegler** from the tropical institute of the MISSIO Würzburg who was for a long time my person of trust. Without his patience, sensibility and persistency in his cause study I would surely have abandoned my work and finally lost my life.

Furthermore, I thank all the colleagues from the BIOTA Africa Project for the great time we spent together on workshops and conferences in several African countries as well as their collaboration in Germany. My special thanks go to Dr. **Meike** Mohneke and

Tillman Konrad who visited me in Malanville and as 'co-sufferers' were always willing to listen to my problems.

In the Zoology III there are some colleagues that supported me during the time of the dissertation especially with their friendship and participation and I am very thankful for this wonderful time. These were **Birgit** Bünger, Dr. **Constanze** Grohmann, **Andrea** Hilpert, **Samuel** Yu-Lung Hsieh, **Dorkas** Kaiser, Dr. **Britta** Kunz, Prof. Dr. **Elisabeth** Obermaier, **Juliane** Steckel and **Marcus** Stüben. My regards also go to **Norbert** Schneider how managed to fabricate different utensils based on my imprecise descriptions.

In this sense I also want to thank the BMBF Germany the **BIOTA**-West that financed the BIOTA Africa Project.

Finally my greatest and perpetual gratitude goes to my **FAMILY**, especially my parents, and **MY FRIENDS** who always believed in me and who kept me grounded during the whole time of the dissertation and especially during these dark periods of my life. Without the support and love of my parents I would never have achieved all this. I am also very thankful to **SESE** who supported and encouraged me during the final spurt and who provided me the possibility and motivation to come more quickly to my happy end.

GENERAL APPENDICES
APPENDIX 1

MATERIAL AND METHODS APPLIED FOR THE CHEMICAL COMPOSITION OF THE FEED AND FEED INGREDIENTS

Prior to the analyses diets and feed ingredients were grind to a fine powder using an electrical coffee grinder machine. Finely, the analyses of the proximate chemical composition of the different materials were based on the procedures of the AOAC (1990). All material were analysed for dry matter (DM), ash, crude protein (CP), crude lipid (CL) and gross energy (GE). The detailed analytic methods are described below:

Dry Matter (DM):

Duplicate samples, each approximately 0.5 g, were weighed into a pre-weighed crucible, heated overnight and subsequently transferred to the desiccator in order to cool off (about 1 h). Finally, crucibles were weighed at room temperature and DM was calculated as follows:

DM [%] = [(crucible weight with samples, g – empty crucible weight, g)/sample weight, g]*100

Ash:

After DM determination, the dried samples were placed in a muffle furnace (Nabertherm) at 500 °C for 6 h. The already weighed crucibles were transferred to the desiccator for approximately one hour and weighed at room temperature. The ash content was calculated as follows:

Ash [%] = (crucible weight with ash, g – empty crucible weigh, g)/sample weight, g

Crude Protein (CP):

Two replicates of approximate 0.2 g were analysed using the “Kjedahl digestion-method”. At first, samples were weighed in nitrogen-free paper, placed in digestion tubes and than digested in 15 ml 96% H_2SO_4 and a Kjeldahl catalyst CX (Gerhard) (0.5 g $CuSO_4$, 0.5 g H_2O and 5 g K_2SO_4) at 400 °C for 90 min using a “Gerhard-heater”. After cooling, samples were distilled with NaOH and titrated with 0.1 N H_2SO_4 using a Büchi

Distillation Unit B-324. Based on this titration values, the nitrogen percentage of the samples was estimated and CP was calculated by multiplying the obtained nitrogen values with the factor 6.25. CP was determined using the formula:
CP [%] = (0.875 * titrated volume, ml/sample weight, g) * 100

Crude Lipid (CL):

The lipid content of the different materials was determined according to Smedes (1999). Two replicates of 0.2 g were weighed in test tubes, well mixed with isopropanol and cyclohexane for 3 min using a vortex and then subjected to an ultrasound bath for 15 min. Subsequently the samples were mixed with double distilled water for 2.5 min and then centrifuged for 5 min at 2700 g. The supernatants were transferred to pre-weighed glass-vials using Pasteurpipettes, while the residues were again suspended with a cyclohexane/isopropanol-mixture, vortexed for 3 min and subjected to ultrasound. The supernatant were gained by iterated centrifugation and added to the previous extracted supernatant. Solvent was than evaporated at 37 °C by placing the glass vials in a heating bloc for approximately 30 min. Adjacent, vials were transferred to a drying oven at 50 °C for 2 h, cooled in the desiccator and then weighed. The lipid content was calculated as follows:
Lipid [%] = (Vial with lipid, g – vial without lipid, g/sample weight, g) * 100

Gross Energy (GE):

Two replicates of approximately 0.25 g were measured for their GE content (MJ/kg) using a bomb calorimeter (IKA-Calorimeter C700 Isoperibolic) based on benzoic acid as standard.

In general, all analyses within these studies were conducted at least in duplicate and the values reported are average of two values. The individual values did not deviate from the mean by more than 5%.

APPENDIX 2

CONSTRUCTION OF THE EXPERIMENTAL PONDS

For the investigation of the feeding trials it was necessary to construct sufficient experimental ponds within the rice cultivating area of Malanville (Fig. 1). Unfortunately the promise that the ponds would be already constructed prior to my arrival proved to be not kept; the only preliminary work accomplished was the control on the depth of the groundwater table. The site provided was a swampy area covered completely by macrophytes (Fig. 2a).

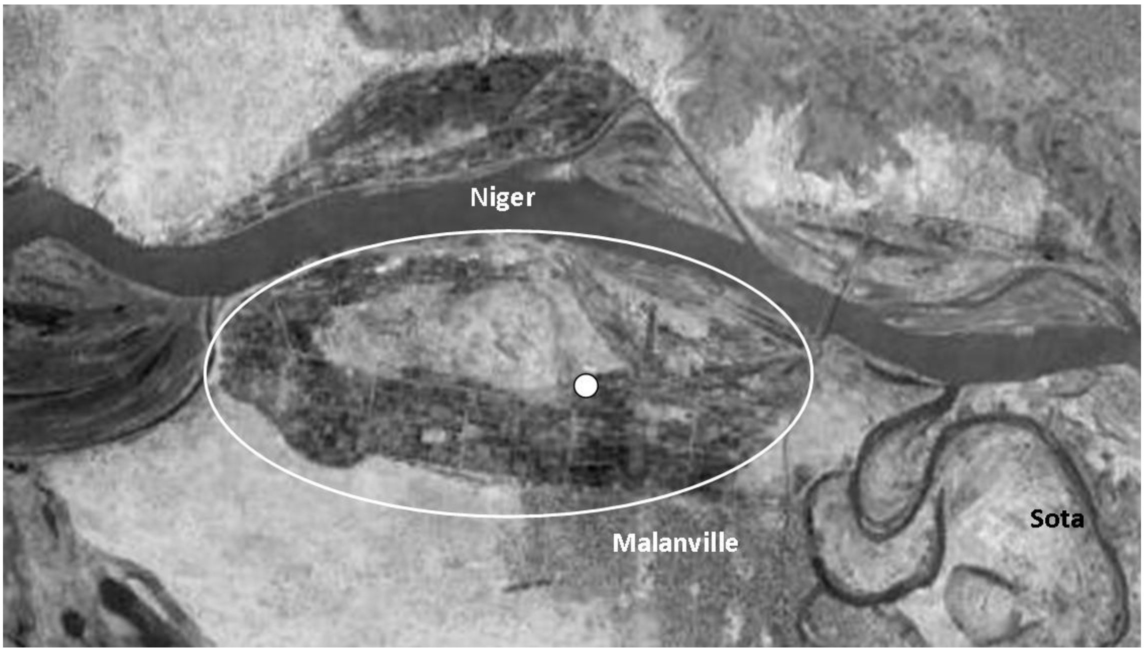


Fig. 1: The picture shows the town Malanville on the north bank of the River Niger with its adjacent rice cultivation area (marked in the white circle and the experimental ponds (white spot). Source: Google Earth; http://www.earth.google.de

Initially, it was planned to construct 18 ponds in order to be able to investigate 5 different materials simultaneously, while having some additional ponds for stocking and handling of the fish. But on arrival at the study site, it emerged that the available area was not only in its raw natural state but also too small to dig 18 ponds. The allocated plot had a length of 33.5 meters and a width of 27 metres and measured approximately 900m^2. This site of 900m^2 was too small and compromises had to be made on the number, and size and shape of the experimental ponds. One compromise was to reduce the number of ponds from 18 to the minimum of 15 necessary for the replicate tests. The other compromise was in squeezing 15 ponds into 900m^2. The result was that the gradient of the banks was unusually steep, unlike commercial ponds. This was satisfactory for the project, but in the longer term rain damage will undoubtedly occur.

The area offered to the Project was in a swamp. To be able to start with the pond construction and to exclude the possibility of the bulldozer getting stuck in the swamp it was essential to drain the area. Therefore, a small dam was built, the channels connecting the site with the adjacent swamp areas and rice fields were closed to ensure that no water could enter the site. After some failures in closing the channels, because somebody re-opened the channels several times, the site needed four days to drain completely.

The next step was the provision of a bulldozer since it was necessary to level the uneven site. Unfortunately this was difficult since all bulldozers in the proximity had been out of order for few months. After 2 months of broken appointments, neglected promises as well as unending talks, an agreement was reached with the construction company that was repairing the road in front of the city hall in Malanville. Finally the bulldozer arrived at the experimental site and completed the levelling in 8 hours.

Subsequently, the bulldozer created a protective bund around the site to avoid the flooding of the experimental ponds during the rainy season (Fig. 2b).


Fig. 2a and b: The study site prior and after levelling by the bulldozer.

That was the end of the mechanised work, and the manual labour began. First of all, the bund around the experimental site had to be arranged and reinforced correctly because the bulldozer just carried out the preliminary work. Then the site was surveyed to plan the size of the ponds, the gradients of the sides and the width of the banks. Each pond measured 7m*4.5 m and they were separated by a 2.5m bank, and a layout for excavation was created using different coloured cords.

All together, more than 24 local assistants were occupied for almost one month to dig the 15 ponds that were aligned in three rows (Fig. 3). Two days after the digging was finished, the ponds were completely filled by inflow of ground water and some corrections were conducted to insure that the ponds have more or less the same water depth. After the completion of the protection dam the channels were reopened to the adjacent fields.

Fig. 3: Manual digging of the 15 experimental ponds

After the first goal was achieved, it was important to protect the bare soil from erosion caused by the heavy rainfalls during the rainy season. Drought-resistant and sun-loving grass seeds (*Cynodon dactylon*) were planted on the dikes. Unfortunately, this was not a success and therefore local plants were transplanted successfully onto the dikes. After the plants had become established, flagstones were collected from a local infrastructure project and used to reinforce the banks and give protection from heavy rain (Fig. 4).

Concurrently with the pond construction, a small store-hut was built for the feed materials and as a shelter for the regularly conducted control harvest and weighing of the fish.

Fig. 4: Ponds after plantation of the dams and their protection with flagstones. The store-hut is visible in the background.

APPENDIX 3

BI-WEEKLY BODY WEIGHT GAIN OF *CLARIAS GARIEPINUS* FED ON DIFFERENT EXPERIMENTAL DIETS

A. Feeding Trial 31.05. to 9.08.2008; Duration of the feeding trial: 60days

Treatment	Whedo No.	Bi-weekly Body Weight Gain in 2008					
		31.05.	**14.06.**	**28.06.**	**12.07.**	**26.07.**	**9.08.**
K a	**14**	26.6	27.7	28.5	26.6	25.9	25.2
K b	**1**	25.6	26.6	26.0	27.1	28.4	25.3
K c	**4**	27.4	28.0	29.5	31.0	26.3	27.3
Mean value Control		**26.6**	**27.5**	**28.0**	**28.2**	**26.9**	**25.9**
T1 a	**3**	24.7	27.9	31.2	31.7	34.8	25.6
T1 b	**5**	25.3	26.3	31.3	30.0	31.3	34.2
T1 c	**8**	29.6	29.7	36.7	38.4	38.1	33.2
Mean value T1		**26.5**	**28.0**	**33.1**	**33.4**	**34.7**	**31.0**
T2 a	**7**	26.7	32.7	36.2	42.3	50.1	37.6
T2 b	**10**	25.9	29.2	36.3	37.8	38.1	39.1
T2 c	**6**	27.9	32.6	36.7	38.8	50.5	41.8
Mean value T2		**26.9**	**31.5**	**36.4**	**39.6**	**46.2**	**39.5**
T3 a	**9**	28.5	32.2	42.5	50.1	50.5	52.8
T3 b	**2**	27.4	31.9	36.9	41.0	48.8	49.9
T3 c	**13**	27.2	34.6	38.0	61.9	60.0	58.8
Mean value T3		**27.7**	**32.9**	**39.1**	**51.0**	**53.1**	**53.8**

APPENDIX 3

BI-WEEKLY BODY WEIGHT GAIN OF *CLARIAS GARIEPINUS* FED ON DIFFERENT EXPERIMENTAL DIETS

B. Feeding Trial 24.02. to 14.07.2009
Duration of the feeding trial: 120 days

Treatment	Whedo No.	Bi-weekly Body Weight Gain in 2009										
		24.02.	**10.03.**	**24.03.**	**7.04.**	**21.04.**	**5.05.**	**21.05.**	**2.06.**	**16.06.**	**30.06.**	**14.07.**
K a	**4**	28.0	26.2	26.2	22.8	26.7	25.6	26.2	25.2	25.9	23.3	25.6
K b	**9**	32.0	29.7	26.1	26.2	26.4	27.0	27.2	25.5	25.9	24.3	26.3
K c	**7**	29.2	29.4	25.0	28.0	28.6	24.0	28.3	24.7	25.9	28.4	26.8
Mean value Control		**29.8**	**28.4**	**25.7**	**25.7**	**27.2**	**25.5**	**27.2**	**25.1**	**25.9**	**25.3**	**26.2**
T1 a	**1**	25.7	31.2	32.7	29.2	31.9	34.8	37.7	37.4	38.3	45.0	47.3
T1 b	**14**	31.8	32.1	36.2	35.0	37.1	37.9	42.5	47.3	49.4	54.8	62.1
T1 c	**3**	28.8	28.5	29.3	32.6	30.8	36.2	35.6	35.9	39.2	40.9	44.4
Mean value T1		**28.8**	**30.6**	**32.8**	**32.3**	**33.3**	**36.3**	**38.6**	**40.2**	**42.3**	**46.9**	**51.2**
T2 a	**13**	29.7	31.7	33.2	36.3	37.5	39.6	44.3	53.0	65.4	66.5	72.3
T2 b	**5**	28.3	33.4	32.9	31.0	36.9	36.1	37.7	38.6	43.4	52.7	57.0
T2 c	**2**	27.9	29.6	32.9	32.8	35.3	40.9	42.1	45.3	50.2	52.2	58.3
Mean value T2		**28.7**	**31.6**	**33.0**	**33.4**	**36.6**	**38.9**	**41.4**	**45.6**	**53.0**	**57.1**	**62.5**
T3 a	**10**	32.0	32.4	30.5	29.7	26.8	36.1	29.5	33.8	36.4	36.9	37.5
T3 b	**8**	28.9	32.2	29.0	27.4	26.3	27.7	25.8	26.7	29.6	29.1	32.7
T3 c	**6**	31.9	28.5	30.6	33.9	27.6	28.9	32.3	33.5	36.7	38.7	41.2
Mean value T3		**31.0**	**31.0**	**30.0**	**30.4**	**26.9**	**30.9**	**29.2**	**31.3**	**34.2**	**34.9**	**31.7**

PUBLICATIONS

PUBLISHED

HAUBER, M., BIERBACH, D. & LINSENMAIR, K. E. 2011a. A description of teleost fish diversity in floodplain pools ('Whedos') and the Middle-Niger at Malanville (North-eastern Benin). Journal *of Applied Ichthyology* 27: 1-5.

HAUBER, M.E., BIERBACH, D. & LINSENMAIR, K.E. 2011a. The Traditional Whedo Aquaculture System in Northern Benin. *Journal of Applied Aquaculture* 23 (1): 67-84.

HAUBER, M.E. 2010. Fish, fisheries and aquaculture: sustainable ways to use natural fish resources and feasible alternatives. *In* 181- 188 Pp. Scientific support for conservation and sustainable use of biodiversity - BIOTA West-Africa: Final Report 2007-2010.

IN PRESS/ ACCEPTED

HAUBER, M., BIERBACH, D. & LINSENMAIR, K. E. 2011b. New records of fish species in the River Niger at Malanville (North-East Benin). *Bulletin of Fish Biology*.

HAUBER, M.E., BIERBACH, D. & LINSENMAIR, K.E. 2011. Whedos - Permanent floodplain pools and their potential for aquaculture. FAO Technical Paper.

IN PREPARTION

HAUBER, M.E., BIERBACH, D. & LINSENMAIR, K.E. Free-floating vegetation of the Whedos in relation to the water parameters.

HAUBER, M.E. & LINSENMAIR, K.E.L. Supplementary feeding of *Clarias gariepinus* (BURCHELL 1822) with locally available by-products in traditional floodplain pools in the North of Benin.

TALKS and POSTER PRESENTATIONS

HAUBER, M., 2007. Improvement of the Aquaculture System in northern Benin. BIOTA West Africa Annual Meeting (7.10. - 13.10.2007) Natitingou, Benin.

HAUBER, M., 2008. Description of the fishery management in the whedos in the North of Benin (Oral presentation). PAFFA Kongress (Panafrican Fish and Fisheries Association) (22.-26.09.08) in Addis Ababa, Äthiopien.

HAUBER, M., 2008. Description of the fishery management in the whedos in the North of Benin (Poster presentation). BIOTA Status Seminary (September/October 2008) in Spier, South Africa.

HAUBER, M., 2010. Improvement of the Whedo System in Malanville, North Benin (oral presentation). Final BIOTA West Workshop (25.-31.01.2010) in Ouagadougou, Burkina Faso.

CONFERENCES AND WORKSHOPS ATTENDED

8.10.-13.10.2007	Workshop of the BIOTA West-Africa Project in Natitingou, Benin.
27.09.-29.09.2007	Workshop of the WorldFish Center in Yaoundé, Cameroon.
22.09.-26.09.2008	PAFFA – Fourth International Conference of the Pan African Fish and Fisheries Association in Addis Ababa, Ethiopia.
29.09.-03.10.2008	Final Conference of the BIOTA Africa Project in Spier/Stellenbosch, South Africa.
27.07. 2009:	Final Workshop with local fish farmers in Malanville (Benin). Topic: 'Management of Fish holes'.
25.01.-27.01.2010	Final Workshop of the BIOTA West-Africa Project in Ouagadougou, Burkina Faso.

CURRICULUM VITAE

Melanie Hauber
Höchbergerstrasse 2
97082 Würzburg
Geboren am 12.07.1980 in Singen am Hohentwiel

Schulische Ausbildung:

1987-1900	Beethoven Grundschule (Singen)
1991-1997	Hegau-Gymnasium (Singen)
1997-2000	Robert-Gerwig Wirtschaftsgymnasium (Singen)
Abschluss:	Allgemeine Hochschulreife

Universitätsausbildung:

2001 – 2005	Universität Kassel, Witzenhausen - ökologische Agrarwissenschaften.
Schwerpunkt:	Internationale Agrarentwicklung (Tropen und Subtropen)
Abschluss:	Diplom Agraringenieurin im September 2005 mit der Note 1,3.

Thema der Diplomarbeit:

'Description of Pond Aquaculture Farming Systems with the Focus on Cameroon and the Formulation of low-cost Supplementary Feeds for *Oreochromis niloticus*'

2005 – 2007	Universität Hohenheim
Masterprogramm:	Agricultural Sciences, Food Security and Natural Resource Management in the Tropics and Subtropics
Abschluss:	Master of Science im April 2007 mit der Note 1,3.

Thema der Masterarbeit:

'Growth performance of Nile tilapia (*Oreochromis niloticus* L.) fed diets containing detoxified *Jatropha curcas* seed kernel meal'.

Seit Juni 2007: Promotion und Projektkoordinatorin im Rahmen des Drittmittelprojekts BIOTA West-Afrika unter der Betreuung von Prof. Dr. K. Eduard Linsenmair, Lehrstuhl Tierökologie und Tropenbiologie der Julius-Maximilians Universität Würzburg.

ARBEITEN im Rahmen der Doktorarbeit:

Feldaufenthalte/Datenaufnahme in Benin (West-Afrika):

1. 5.08. - 16.10.2007
2. 17.02. - 16.08.2008
3. 14.01. - 25.05.2009
4. 5.06. - 4.08.2009
5. 1.02. - 14.02.2010

Durchführung von Futtermittelanalysen im Labor des Institutes für Tierernährung in den Tropen und Subtropen, Universität Hohenheim:

1. 19.07. - 31.07.2007
2. 10.01. - 12.01.2008
3. 28.10. - 1.11.2008
4. 1.12. - 4.12.2008

Vorbereitung und Leitung eines Workshops am 27.07. 2009:

'The Management of Fish holes' in Malanville, Benin.

Erfahrungen und berufliche Tätigkeiten:

09.2000 - 03.2001 FÖJ im Biologischen Gemüseanbau; Heydenmühle; Otzberg-Lengfeld; Besitzer: Johannes Fetscher.

03.2001 - 09.2002 Praktikum für das Landwirtschaftsstudium im Milchviehbetrieb; Wiechs; Deutschland; Besitzer und Ausbilder: Reinhold Zimmermann.

08.2003 – 09.2003 Praktikum in der Entwicklungshilfeorganisation; MIDENO; Bamenda; Kamerun; Verantwortliche: Mary Ngé.

09.2004 – 03.2005 Praktikum im World Fish Center; Yaoundé; Kamerun; Koordinator: Randy Brummett.

05.2006 - 08.2006 HiWi im Institut für Aquakultur und Tierernährung in den Tropen und Subtropen; Universität Hohenheim; Institutsleiter: Prof. Becker.

10.2006 -12.2006 Wissenschaftliche Hilfskraft im Institut für Aquakultur und

	Tierernährung in den Tropen und Subtropen; Universität Hohenheim; Institutsleiter: Prof. Becker.
3.03. - 18.03.2007	Exkursion im Rahmen des Masterstudiengangs, Besichtigung der Untersuchungsgebiete des Sonderforschungsbereiches in Thailand: 'Sustainable Land Use and Rural Development in Mountainous Regions of Southeast Asia'.

Würzburg, im Mai 2011

(Melanie Hauber)

AUTHOR'S DECLARATION

I hereby declare that this work is the result of original experimental work carried out by myself. Research was done, using existing literature to support my findings and any assistance has been duly acknowledged. I further declare that the results of this research have not been submitted for the award of any other degree.

ERKLÄRUNG

Gemäß § 4. Abs. 3 Ziffer. 3, 5 und 8
der Promotionsordnung der Fakultät für Biologie

Hiermit erkläre ich ehrenwörtlich, dass ich die vorliegende Arbeit selbständig angefertigt und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe.

Die Dissertation hat meines Wissens weder in gleicher noch in ähnlicher Form in einem anderen Prüfungsverfahren vorgelegen.

Von der Universität Kassel, Witzenhausen wurde mir das Recht verliehen mich als Dipl. Ingenieurin, sowie von der Universität Hohenheim mich als Master of Science zu bezeichnen. Darüber hinaus habe ich keine akademischen Grade erworben und auch nicht versucht diese zu erwerben. Aufgrund meiner fachfremden Ausbildung holte ich mir bereits am 24.02.2007 die Zulassung zum Promotionsverfahren als Diplom-Agraringenieurin zur Erlangen des Dr. rer. nat im Bereich der Fakultät für Biologie am Lehrstuhl der Zoologie III ein. Die Zulassung erhielt ich durch Prof. Dr. Dr. Th. Dandekar, Dekanat für Biologie.

Würzburg, im Mai 2011

(Melanie Hauber)