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A CASE STUDY: FISH PRODUCTION IN THE INTEGRATED FARMING SYSTEM OF THE BLACK THAI IN YEN CHAU DISTRICT (SON LA PROVINCE) IN MOUNTAINOUS NORTH-WESTERN VIETNAM - CURRENT STATE AND POTENTIAL

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III List of Abbreviations

ADF	Acid detergent fibre
BHC	Bighead carp
BW	Body weight
BWG	Body weight gain
CA	Crude ash
CAF	Catfish
CC	Common carp
CF	Condition factor
CK1	Case study farm 1 in Chieng Khoi commune
CK2	Case study farm 2 in Chieng Khoi commune
CK3	Case study farm 3 in Chieng Khoi commune
CP	Crude protein (N x 6.25)
CSF	Case study farm
CSP	Case study pond
DFG	Deutsche Forschungsgemeinschaft
DM	Dry matter
DO	Dissolved oxygen
EE	Ether extract
FAO	Food and Agriculture Organization of the United Nations
FCR	Food conversion ratio
FM	Fresh matter
GC	Grass carp
GCHV	Grass carp haemorrhage virus
GDP	Gross domestic product
GE	Gross energy
GPS	Global positioning system
HCN	Hydrocyanic acid
HEPR	Hunger Eradication and Poverty Reduction (programme)
HH	Household
HSI	Hepato-somatic index
HUA	Hanoi University of Agriculture
IAA	Integrated agriculture-aquaculture
Ind	Individual
IPM	Integrated pest management
L	Lignin
MC	Mud carp
MRI	Mrigal
N	Nitrogen
n.a.	Not available
n.d.	Not determined
n.r.	Not reported
NDF	Neutral detergent fibre
no	Number
PER	Protein efficiency ratio
PI	Pirapitinga
RIA-1	Research Institute of Aquaculture No. 1
RIL	Relative intestine length
ROH	Rohu
RSD	Red Spot Disease

SAPA	Sustainable Aquaculture for Poverty Alleviation (Programme)
SB	Silver barb
SC	Silver carp
SDD	Secchi disk depth
SGR	Specific growth rate
SL	Son La
SRS	Self-recruiting species
SV1	Case study farm 1 in Sap Vat commune
SV2	Case study farm 2 in Sap Vat commune
SV3	Case study farm 3 in Sap Vat commune
T	Water temperature
TIL	Tilapia
UHOH	University of Hohenheim
UNDP	United Nations Development Programme
VAC	Vietnamese farm systems, in which garden, fishpond and livestock pen are integrated (Vietnamese acronym)
VL1	Case study farm 1 in Vieng Lan commune
VL2	Case study farm 2 in Vieng Lan commune
VL3	Case study farm 3 in Vieng Lan commune
VND	Vietnamese dong (Currency)
WTO	World Trade Organization
YC	Yen Chau (District)

Units

°C	Degree Celsius
cm	Centimetre
d	Day
g	Gram
ha	Hectare
kcal	Kilocalorie
kg	Kilogram
kJ	Kilojoule
km	Kilometre
l	Litre
m	Meter
m^2	Square meter
m^3	Cubic meter
mg	Milligram
mil	Million
MJ	Mega joule
mm	Millimetre
mV	Millivolt
t	Tons
yr	Year
µm	Micrometer

Exchange rate

1 US$ equivalent to 15 870 VND

1 Introduction

Aquaculture is one of the fastest growing food production systems in the world and, correspondingly, aquaculture products are likely to witness an increase in demand and importance in the future (Pedini and Shehadeh, 1997; FAO, 2002; Delgado et al., 2003). Relevant to this change is the fact that wild fish stocks have been fully or over-exploited on a global level. In addition, the worldwide consumption of fish has doubled since 1973; developing countries constitute 90% of this growth with Asia being the top consumer and producer of aquaculture products. Despite the rapid growth rates, the per-capita consumption of fish remains much lower in developing countries compared to developed countries (Delgado et al., 2003).

When considering Vietnamese aquaculture, shrimp or catfish might be the first products that come to mind. Both are produced rather intensively in coastal regions and the major river deltas. They are considered medium- to high-value commodities, produced primarily for the more prosperous classes of the local population and global markets. Not only are these aquaculture systems often associated with a number of adverse environmental impacts (e.g. Naylor et al., 2000), but also these products are usually not affordable for the poor. However, it is often forgotten that in Vietnam a large volume of aquacultural products is consumed locally. This comprises mainly low-value carp species, which feed low in the food chain (e.g. Beveridge and Haylor, 1998) and are commonly produced in extensive or semi-intensive freshwater aquaculture (Institute for Fisheries Economics and Planning, 1996; Van et al., 2002).

The production of fish through aquaculture practices has traditionally played an important role in providing fish to the Vietnamese people (Barg, 1997; Edwards, 2000). In Vietnam, 30-35% of the population's total animal protein intake comes from fish (Barg, 1997; Laureti quoted in Tacon, 1997a; Subasinghe et al., 1997). It is widely acknowledged that fish constitutes an important component of the human diet. Fish and other living aquatic resources are considered to be nutrient-dense foods, which provide protein, fatty acids, minerals and vitamins (e.g. Prein and Ahmed, 2000). Although the low-income population in developing countries consumes relatively low amounts of fish, they often rely on fish as a major source of animal protein in their diets (Kent, 1997). Despite a global increase in fish consumption (Delgado et al., 2003), these rates have been declining in many low-income, food-deficit countries. It may even decline further as a result of overexploitation of natural fish resources and perceived demographic trends (Prein and Ahmed, 2000).

However, Vietnam may experience an expansion in markets for aquaculture products. This is based on an increase in domestic demand for fish caused by continuous population growth, an increase in per capita income (Worldbank, 2006) and an increase in per capita fish consumption (Fisheries Informatics Centre, 2006). However, aquaculture production may fail to keep up with domestic markets and an increasing local demand; therefore, if production efficiency does not improve, a raise in fish prices is likely, making these products unaffordable for Vietnam's poor. Lower domestic supplies of fish may have serious consequences for low-income people with fish-dependent diets (Kent, 1997). Fish as a food group tends to have high income elasticity (Dey, 2000; Prein and Ahmed, 2000). In the case of rising prices, it is likely that the poor would cut back more on fish consumption in relation to the rich. Delgado et al. (2003) modelled a scenario predicting the global development of fish prices until the year 2020 by using plausible assumptions; with this model, they estimated a general price increase of 6% in the case of low-value fish such as carp.

An increase in the domestic supply of affordable fish, produced locally in small-scale integrated agriculture-aquaculture systems, could allow the poor to consume those nutritionally rich products and in addition improve the incomes of resource-limited fish farmers. Vietnamese aquaculture is actually considered profitable work, as expressed in Vietnamese proverbs: "*nhất canh trì, nhì canh viên, ba canh điền*" (first aquaculture, second horticulture and third agriculture) and "*nhất thả cá, nhì gá bạc*" (first aquaculture, second gambling). It has widely been recognized that encouraging the further development of aquaculture production can contribute in a sustainable manner to food security and poverty alleviation in developing countries (Tacon, 1997a; Edwards, 2000; Prein and Ahmed, 2000).

Vietnam is developing at a fast pace, but despite the economic gains, Vietnam is still considered a low income country with a per capita Gross National Income (Atlas Method) of only 620 US$ in 2005 (Worldbank, 2006). The poorest people in Vietnam are often found among the members of the country's ethnic minorities as well as the population in remote areas such as the northern mountainous areas (ARMP, 2000; ADB, 2002; Rural Poverty Portal, 2006). Located in this mountainous region of north-western Vietnam, Son La is considered to be one of the poorest provinces in the country with the third highest poverty rate out of all Vietnamese provinces (Minot et al., 2003). This area is considered being vulnerable due to its physical features, which force farmers to practice agriculture on steep slopes (Wezel et al., 2002a,b). Several ethnic groups, such as the Black Thai and Hmong minorities, have settled in this region and adapted to the different biophysical environments, which has led to the development of varying land use and farming systems. Up to now, local knowledge of farmers regarding the management of these natural resources in this challenging environment is poorly documented.

In the district of Yen Chau in the Son La province, settlements of the ethnic Black Thai minority are located on the valley bottoms with paddy fields constituting the major crop. In addition, maize, cassava and occasionally cotton are produced as cash crops on the hillsides and vegetables and fruits are grown in home gardens. Common farm animals include poultry, ruminants and pigs, but fish farming is also a common activity in this region. Fish are raised in cyprinid-based polyculture ponds with constant water-flow during most of the year. Ponds are often located in residential, paddy or rain-fed upland areas and are integrated into the overall farming and irrigation systems. Crop residues, leaves, weeds as well as manure from large ruminants and pigs serve as nutrient inputs.

Although the aquaculture system exhibits elements associated with rather intensive systems, such as being feed-based and having frequent water exchange (Edwards et al., 1988), officially reported annual fish yields are relatively low with only 1.63 tons ha^{-1} $year^{-1}$ (Annual report for 2004, Statistical Office Yen Chau, unpublished data) compared to other integrated carp polyculture systems in Northern Vietnam, which report yields of over 6 tons ha^{-1} during one production season of 9 months (Luu et al., 2002). In 2005, the average price for fish on the local market was approximately 1.4 US$ kg^{-1}, which is considered to be relatively high, particularly when comparing this amount to the monthly per capita income of approximately 13.4 US$ in Son La (General Statistic Office, 2004). Fish prices in the mountainous regions are reported to be higher than those in the capital city of Hanoi (ARMP, 2000), indicating that local fish demand is higher than the supply, leaving farmers a potential scope for increasing their fish production.

To date, there has not been any research published that focuses on the upland aquaculture system of the Black Thai farmers in this area. The need for a description of actual and potential integrated agriculture-aquaculture systems in Southeast Asia has been stressed by Edwards and Little (1995). Secondary data on aquatic resource utilization by poor populations is limited in Vietnam and its importance is often overlooked in official data (ARMP, 2000). A lack of reliable data on small-scale aquaculture is an issue throughout Southeast Asia since much of the production is consumed by the local households and is excluded from national statistics. The many differences as well as the dynamic resource systems present inherent difficulties in assessing production (ARMP, 2000). In addition, farmers seldom keep records of operation and production, and those who do are rarely willing to provide accurate information (Ling, 1977). However, a solid analysis of the current status is indispensable for future interventions.

Within the framework of the Special Research Program on "Sustainable land use and rural development in mountainous regions of Southeast Asia" (SFB 564, "The Uplands Program") funded by the German Science Foundation (Deutsche Forschungsgemeinschaft, DFG), a survey on aquaculture practices has been carried out in Yen Chau from January 2004 to June 2006. This research was conducted in order to obtain a detailed description of the status quo of the local integrated aquaculture system with its potentials and limitations. Possible causes for the relatively low productivity were analyzed and the potential for improved management schemes were identified. In the second step, these management schemes need to be tested *on farm* in close cooperation with local farmers.

The data was collected and analyzed on three different levels. On the "macro level", general data is presented regarding the land use and irrigation system in the studied area (chapter 3.1 and 4). On the "meso level", information about the general aquaculture and agriculture system is provided based on interviews with farmers and other stakeholders (chapter 3.2 and 5). The "meso" part takes into account such issues as the general pond system, farmers' fish stocking, feed, manure, harvesting behaviours, the integration of aquaculture in the overall irrigation as well as farming systems and limitations and problems associated with the local fish production. On the "micro level", supplementary data that cannot be gathered through interviews alone is added (chapter 3.3 and 6). Here, an in-depth investigation based on close observations of selected case study farms is presented. This data includes the limnological pond conditions, fish stocking densities, fish growth rates, fish yields, type and amounts of feed, addition of manure, conversion of feed to fish body mass and an evaluation of the profitability of the aquaculture system.

Several authors have called for holistic and multidisciplinary systems approaches in aquaculture research so that the aquaculture system can be accurately understood, particularly when it is integrated with agriculture (Grove and Edwards, 1993; Edwards and Little, 1995; Edwards et al., 1996a; Edwards, 1998). The approach in the presented study considers not only information gathered from interviews but also measured pond data, focussing on an overall understanding of the aquaculture system in its context and interrelations with other systems. Such a broad view is required in order to tailor location-specific solutions, which have the potential to improve the livelihoods of the farmers in an economically, socially and ecologically sustainable way.

2 Literature-based background information

2.1 General characteristics of the study area

2.1.1 Son La province and Yen Chau district: Location and population

The term "Son La" is derived from the Vietnamese words "*Son*", meaning mountain, and "*La*", meaning stream. Son La province is situated at a longitude of 21.2° and a latitude of 103.5° and is located at an altitude of approximately 600 m above sea level (Hung, 2003). It shares a border with Laos and other Vietnamese provinces and consists of Son La town and 9 districts, e.g. Yen Chau district. Figure 1 shows the position of Son La province in Vietnam along with its districts. In 2003, a total of 942 000 people belonging to 12 different ethnic groups live in this province. 85% of labourers work in rural areas, their main sources of income derive from activities in agriculture, forestry and fisheries (Hung, 2003).

Figure 1: Position of Son La province and its districts in Vietnam (source of map: The Uplands Program, unpublished and modified)

The Yen Chau district is divided into Yen Chau town and 13 communes, each consisting of several villages. Around 32% of the total district area (86 610 ha) is agricultural land, and 3% of the total area is irrigated (Khiem and Van der Poel, 1993). 63 191 people (13 597 households) live in the district, of which approximately 5.5% reside in Yen Chau town. The main ethnic group is Black Thai, accounting for almost 54% of the district population. 21% of the population belongs to Kinh, the major ethnic group in Vietnam. Approximately 13% and 12% belong to the H'Mong and Sinh Mun minorities respectively

(Statistical Office Yen Chau, state 2004, unpublished). The settlements in this region are predominantly located in the valleys (Khiem and Van der Poel, 1993). Khiem and Van der Poel (1993) estimate that an average of 1.2 ha (0.2-4.9 ha) of land is cultivated per Yen Chau household.

2.1.2 Climatic conditions in north-western Vietnam and Yen Chau

The climate of mountainous North-western Vietnam is characterized by low temperatures, hoarfrost, little rainfall in the winter and high precipitation accompanied by hot temperatures in the summer. Local microclimates can vary strongly between places (Kiem and Van der Poel, 1993). According to the Metrological Station in Yen Chau (unpublished), average temperatures (average based on monthly records) were around 25°C in 2004 and 23.1°C in 2005. The total precipitation was approximately 1 140 mm in 2004 and 1 448 mm in 2005. The monthly average temperatures and amount of precipitation in those years are presented in Figure 2. Mean air humidity was 79% in 2004 and reached 81% in 2005.

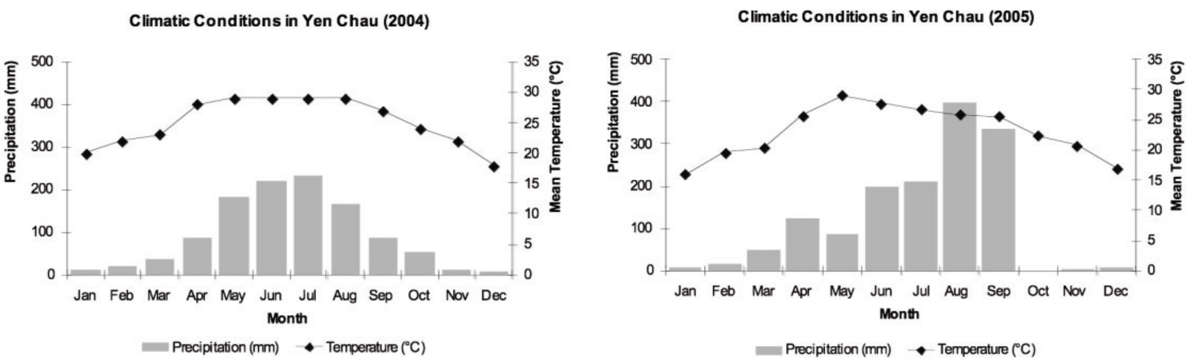


Figure 2: Precipitation and mean temperatures in the years 2004 and 2005 in Yen Chau district (Meteorological Station Yen Chau, unpublished)

2.1.3 Specific geographical characteristics of Son La and Yen Chau

Limestone karsts cover wide parts of the Son La province (Khiem and Van der Poel, 1993) as well as the Yen Chau district (Stahr and Clemens, pers. commun.). Soil types vary between regions due to the different underlying parent materials and strongly varying weather conditions. However, limited information is available regarding soil types and properties in the region (Clemens, pers. commun.). They are generally characterized by strong ferraltic processes, especially in lower altitudes, and tend to be acidic and low in nutrient content (Khiem and Van der Poel, 1993). In this area, the occurrence of soil degradation is common, caused by the practice of agriculture on very steep slopes (Khiem and Van der Poel, 1993; Wezel et al., 2002a,b).

2.1.4 Administrative structures

Vietnam's governmental system is decentralised. At the province level, the People's Committees are responsible for local political and economic issues. Lower administrative units include the People's Councils and People's Committees on the district and communal level. Each commune consists of several villages with a village headman acting as a centralized executive figure (Khiem and Van der Poel, 1993).

2.1.5 Land allocation

In the Vietnamese Law of Land of 1993, it is stated that "land is the property of the entire people, uniformly managed by the state", "the state shall allocate land to ..., households and individuals for stable and long-term use" and "...households or individuals shall be entitled to exchange, transfer, lease, inherit, mortgage the land use rights" (unofficial translation by La and Anson, 1997). Land is allocated to households for fixed periods of time, i.e. in the case of agriculture, up to 15-20 years (Khiem and Van der Poel, 1993). A so-called "Red Book Certificate" indicates that land is legally allocated to the farmers (Rake et al., 1994).

2.1.6 The ethnic Black Thai minority

"Thai" is one of 54 ethnic groups known in Vietnam and is mainly concentrated in the provinces of Son La, Nghe An, Thanh Hoa and Lai Chau (Dien, 2002). Approximately 1.2 million people of this Thai ethnic group reside in Vietnam (ADB, 2002). According to their own records, their ancestors arrived in Vietnam either from China or Thailand in the ninth century (Dien, 2002). The group that came from Thailand travelled via the Mekong River to different regions including to the district Yen Chau. Now, Thai consists of two groups in Vietnam, the White Thai ("*Thái Trắng*") and Black Thai ("*Thái Đen*") (see Dien, 2002). Thais distinguish themselves by a common language (also called "Thai"), typical clothing style and the stilt houses resembling the shape of tortoise shells. They usually settle in valleys and along rivers or streams, where they cultivate paddy rice and construct dams and dig cannels for irrigation of these fields. Ethnic minorities like the Thai face various issues in Vietnam including limited land, cultural isolation, poor infrastructure and poor access to extension services (ARMP, 2000).

2.2 Fish production in Vietnam with special reference to Son La and Yen Chau

2.2.1 Quantities and impact of fish production in Vietnam

According to official statistics released by the Fisheries Informatics Centre (2006), the total aquaculture area in Vietnam comprised nearly 870 000 ha in 2003. In 2004, the total aquaculture production reached more than 1.2 mil tons, of which freshwater finfish production contributed approximately 760 000 tons. Freshwater finfish, accounts for more than 61% of the total aquaculture production quantity (see Figure 3) but only 46% of its value (FAO, 2006a).

Vietnamese aquatic products are either supplied to domestic or export markets. In 2004, crustaceans accounted for 53% of the total value of fisheries export (FAO, 2006a). Typical aquaculture products within the domestic markets include carp, which are usually traded, either alive or fresh, and are rarely processed (FAO, 2006b). The fisheries sector, which includes aquaculture, plays an important role in the economy of Vietnam and has contributed more than 3% of the national GDP (gross domestic product) over the last few years (FAO, 2006c; Fisheries Informatics Centre, 2006). In 2000, fisheries' total export earnings was approximately 1.47 billion US$ (Fisheries Informatics Centre, 2006). In 2003, the national aquaculture sector provided employment for approximately 2.5 million people, as either part- or full-time workers. Furthermore, to relay the importance of this industry on a domestic level, the estimated annual per capita consumption of fish increased to 19 kg in 2006 (Fisheries Informatics Centre, 2006).

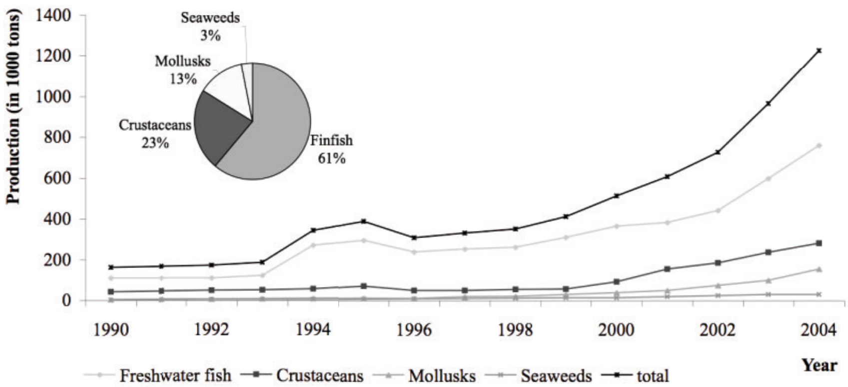


Figure 3: Development of aquaculture production in Vietnam and amounts of different aquatic products in 2004 (FAO, 2006a)

2.2.2 History of fish culture in Vietnam

In Northern Vietnam, traditional aquaculture systems have a long history, probably influenced by neighbouring China (Edwards et al., 1996a). In the past few decades, two main stages have been observed in the development of the aquaculture sector in Vietnam: an initial period from 1960 to 1980 and the period from 1981 onwards. In the early 1960s, the aquaculture sector in Vietnam began with small-scale extensive aquaculture systems, such as rice-cum-fish, livestock-cum-fish and fish production in earthen ponds. During the Vietnam War (1963-1975), aquaculture activities were also supported and promoted in order to improve the food base for the people and military. The second stage is characterized by shrimp farming for export; many farmers started switching to species suitable for export, such as giant tiger prawn, catfish, lobster and grouper (FAO, 2006c).

2.2.3 Recent development of fisheries policy in Vietnam

In order to address the Vietnamese government's goal to eradicate hunger and reduce poverty, the programme "Hunger Eradication and Poverty Reduction" (HEPR) was developed. The Ministry of Fisheries played a limited role in the first decade of the HEPR programme, since it mainly focussed on industrial and commercial scale development of aquaculture (ARMP, 2000). The contribution of aquaculture as a tool for hunger eradication and poverty alleviation has been acknowledged by the Vietnamese government and recently addressed by the Ministry of Fisheries with the development of a special initiative, "Sustainable Aquaculture for Poverty Alleviation" (SAPA). SAPA was initiated by the Food and Agriculture Organization of the United Nations (FAO) in 1999 (Van Anrooy and Evans, 2001) and is integrated in the umbrella HEPR programme. The primary target group of SAPA are "poor people in rural areas, where opportunities exist to diversify and improve livelihoods through aquaculture" (Luu, 2001a; Van Anrooy and Evans, 2001) with special attention given to the most vulnerable regions, e.g. in the northern mountains (Luu, 2001a). Although this program exists, the author of the present book is not aware of its current stage of implementation.

2.2.4 Typical fish farming systems and their regional distribution in Vietnam

In Vietnam, many different aquaculture systems are found across the country, which include inland, marine and brackish water systems, all in different stages of intensification. While the North is mainly dominated by culture systems such as freshwater fishponds, rice-cum-fish and marine culture, farmers in the central regions mainly concentrate on the farming of giant tiger prawn as well as marine cage culture of finfish and lobster. Diverse aquaculture systems are found in the South, e.g. pond, fence and cage culture of catfish as well as indigenous species (e.g. snakehead, climbing perch). In the South, there is also shrimp production in different stages of intensification as well as integrated systems such as rice-cum-fish, rice-cum-prawn and mangrove-cum-aquaculture (FAO, 2006c).

2.2.5 Fish production in the Son La province

In the Son La province, nearly 46 000 people worked in the aquaculture sector in 2003 (Fisheries Informatics Centre, 2006). Here, the freshwater aquaculture areas for fish production comprise approximately 1 450 ha. In this area, a total of 2 381 tons of freshwater fish were produced in 2003 (Fisheries Informatics Centre, 2006). Based on this data, the mean fish productivity for this time would be 1.64 tons ha^{-1} $year^{-1}$. The Institute for Fisheries Economics and Planning (1996) cautions against the inaccuracy of an interpretation of the quantitative data regarding the aquaculture resources in Vietnam. A significant part of aquaculture takes place in seasonal water bodies, which is often not reflected in those statistics. Additionally, the amount of local household consumption of fish is often overseen and not monitored.

2.2.6 Fish production in the Yen Chau district

Table 1 shows statistics on fish production in the Yen Chau district. According to the Statistical Office of Yen Chau (unpublished), more than one-third of all households in this district produce fish (state: 2004). Fish production is mainly concentrated in the valleys along the streams in regions that are mainly settled by Black Thai and Kinh. According to the Statistical Office, aquaculture activities have continued to expand over the last few decades. In 2004, the average pond size of a fish farming household was 445 m^2 and the average productivity 1.63 tons ha^{-1}.

Table 1: Fish production in Yen Chau in 2004 and 2005 (source: Statistical Office Yen Chau, unpublished data)

Fish production in Yen Chau	Unit	2004	2005
Households raising fish	Households	4790	4814
Total pond area	ha	213.0	217.9
- Grow-out ponds	ha	211.7	216.7
- Nursery ponds	ha	1.3	1.2
Total fish yields			
- Yield of marketable fish	tons	346	326
- Yield of nursery fish	1000 fish	1 000	980
Average pond productivity			
- Grow-out ponds	tons ha^{-1}	1.63	1.5
- Nursery ponds	1 000 fish ha^{-1}	757.5	803.2
Yield of fish caught from natural sources	tons	27	22
Percentage of fish for sale	%	35	41
Percentage of fish for consumption	%	65	59

2.2.7 Typical fish species produced in Vietnam

A wide range of species are used in freshwater aquaculture systems in Vietnam. In southern Vietnam, catfish, giant river prawn, climbing perch and Indonesian snakehead are popular species; however, carp polyculture is by far the most commonly practiced system in the country (Institute for Fisheries Economics and Planning, 1996; Van et al., 2002). Typical cyprinid species produced in Vietnam are grass carp, silver carp, common carp, bighead carp, silver barb, mud carp and Indian carp such as mrigal. Also, the production of the cichlid Nile tilapia is common (Institute for Fisheries Economics and Planning, 1996). Specific statistical data regarding quantities of carp species cultivated in Vietnam is lacking (Institute for Fisheries Economics and Planning, 1996; FAO, 2006a).

2.3 Production of carp and tilapia

Cyprinids are by far the largest group of cultured aquatic animals in the world, accounting for almost a third of the worldwide aquaculture production and 64% of the total finfish production on a quantitative basis in 2004 (FAO, 2006a). Figure 4 shows the total cyprinid production split according to major carp species. Grass carp, silver carp and bighead carp are usually attributed to Chinese carps, while mrigal, rohu and catla are Indian major carps (e.g. Beveridge and Haylor, 1998). The production of cyprinids has been associated with a number of advantages: they feed low in the food chain (Pedini and Shehadeh, 1997; Beveridge and Haylor, 1998), can be raised in a polyculture system and have good markets in Asia due to tradition and relatively low prices (Pedini and Shehadeh, 1997). Also, tilapia shows a tremendous growth in output (FAO, 2006a). Table 2 shows some characteristics of typical carp species and tilapia that are produced in Vietnam.

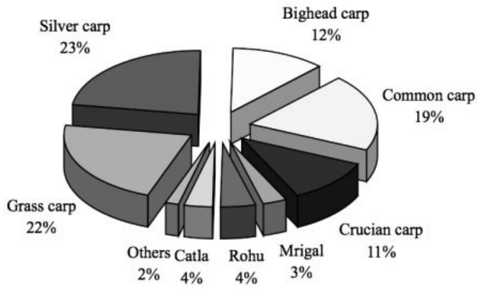


Figure 4: Worldwide shares of different carp species within the total cyprinid production in tons in 2004 (FAO, 2006a)

2.3.1 Production of grass carp

The worldwide production of grass carp has increased from roughly 10 500 in 1950 to almost 3.9 mil tons in 2004, accounting for more than a fifth of the total world carp production and almost 7% of the total global aquaculture production (FAO, 2006a). The major producer is China, where this fish species is traditionally eaten fresh and only rarely processed (FAO 2006a,b). Grass carp is usually marketed and consumed locally and is considered a low-value commodity, which has the advantage of being affordable for the middle- and low-income classes. In addition, grass carp have low requirements for dietary protein, can be produced at low costs due to their feeding habits, have a rapid growth potential, reach relatively large sizes, lack fine inter-muscular bones (FAO, 2006b) and are able to withstand a wide range of temperatures (Ling, 1977). However, an important constraint in grass carp production is their susceptibility to diseases (FAO, 2006b).

Table 2: Selection of important fish species produced in Vietnam (Institute for Fisheries Economics and Planning, 1996) and some of their characteristics (FAO, 2006b; in case of silver barb: Fishbase, 2006a); Table to be continued

Fish species and family	Feeding behaviour (adult fish)	Seed supply	Habitat and special characteristics/requirements	Grow-out techniques (examples)
Grass carp (*Ctenopharyngodon idella*), Cyprinidae	Herbivorous, naturally feed on certain aquatic foods; under culture conditions, feed on by-products from grain processing, pellet feed, aquatic weeds, terrestrial grasses	GC can reach sexual maturity under culture conditions but cannot spawn; induced spawning in tanks by hormone injection and flowing water required	Mid water column level; prefer clean water, prefer water with low fertility, production mainly limited by water quality	Mainly semi-intensive and intensive polyculture in ponds, pens and cages in open waters In Vietnam: earthen ponds or cages, polyculture with other species, e.g. SC, CC; fed with terrestrial grasses, cassava leaves, banana stems and maize leaves in grow-out culture; GC usually accounts for 60% of total production (7-10 tons ha^{-1}); marketing sizes 1-2.5 kg
Silver carp (*Hypophthalmichthys molitrix)*, Cyprinidae	Herbivorous, benthopelagic, low in the food chain, gill rakers serve as main means of filtration; feeds include dinoflagellates, chrysophytes, detritus, conglomerations of bacteria, small crustaceans	Insufficient hormone secretion under artificial conditions; induced spawning by hormone application and choice of suitable season etc.	Temperate conditions (6-28°C); swim near water surface, cleanse water of clogging algae	Typically 2-year-culture cycle in China; possible systems: a) polyculture; b) continuous harvesting and stocking (mainly BHC and SC); table sizes 0.75-1.5 kg
Bighead carp (*Aristichthys nobilis*), Cyprinidae	Natural food (zooplankton); can be produced through organic fertilization or the use of wastes from other fish in a polyculture system	One spawning season per year; slow gonadal development; cannot spawn under captivity; hormone injection and e.g. flowing water required for induced spawning	Eurythermic fish, able to tolerate temperatures between 0.5-38°C; dwell in upper layer of the water column, prefer highly fertile water with abundance of natural food, slow growth in the early developmental stage	Extensive culture mainly in open waters and pond-based polyculture In Vietnam: polyculture with other species, e.g. GC, SC, MRI, CC, TIL; usually 3-5% of total stocked species; 5-7% of total production; no special feeding for BHC, market size: 2.5-3 kg; smaller fish have limited meat quality and many fine inter-muscular bones
Common carp (*Cyprinus carpio*), Cyprinidae	Omnivorous, high tendency towards food of animal origin, such as aquatic insects, larvae of insects, worms, molluscs, zooplankton; additional foods include stalks, leaves and seeds in aquatic and terrestrial plants, decayed aquatic plants, cereals etc.	CC can spawn e.g. in ponds; Asian strains spawn when water ion concentration decreases abruptly in the beginning of the rainy season; hatchery based seed production most effective and reliable method	Mainly bottom dwellers, but search for food in the middle and upper layers of water body; broad environmental tolerance, best growth between 23-30°C; can also survive in cold winter periods and also at low DO levels	Extensive, natural food and supplementary feed-based monocultural production in stagnant ponds; artificial feed-based monocultural production systems in cages, irrigation reservoirs and running water ponds, etc.; natural foods and supplementary feed-based production in polyculture (e.g. other cyprinids); CC integrated with animal husbandry or plant production; CC often key species in integrated systems. CC can reach body weights of 0.6-1 kg within one season in polyculture ponds in the tropics

Table 2 continued

Mud carp (*Cirrhinus molitorella*), Cyprinidae	Omnivorous, feed on organic detritus, filamentous algae and pieces and seeds of aquatic weeds; natural food and commercial feed, e.g. by-products from grain processing and oil extraction	Can reach sexual maturity in aquaculture, unable to spawn unless induced by hormone injection and flowing water is present	Bottom-dwellers; prefer clean water; can move swiftly; can not tolerate temperatures < 7°C; difficult to harvest without draining of pond	Typical production method: polyculture in ponds; grow slowly and reach smaller sizes than GC, BHC, SC; production of MC either as major species (e.g. MC, GC, BHC as main species and SC, TIL, CC as secondary species) or secondary species, also together with other carp species; MC typically reach 125-200 g after one year of rearing in those system where they are stocked as the main species
Mrigal (*Cirrhinus mrigala*), Cyprinidae	Illiophagous and stenophagous; detritus and decayed vegetation make up principal food components; also phyto- and zooplankton serve as feed; fertilization with organic manures and inorganic fertilizers, supplementary feeding with e.g. mixture of rice bran and oil cake	Can not breed in pond; induced breeding by hypophysation and use of synthetic hormones	Bottom-dwellers; eurythermal, tolerate minimum temperature of 14°C; difficult to harvest, complete harvesting only possible through draining	Confined to earthen ponds, mainly produced as a component of carp polyculture systems; e.g. in Vietnam also as one of the principal components in carp polyculture systems; usually cultured with other Indian major carps (rohu, catla) or in combination with 2 Indian major and Chinese carps (e.g. GC, SC) and CC In culture, MRI attains 600-700 g in the first year; usual production of 3-5 tons ha^{-1} $year^{-1}$ (stocking density MRI 20-25%); normally ≤ 2 years of raising period; afterwards, reduction in growth rate
Silver barb/Java barb (*Barbus gonionotus*), Cyprinidae	Feed on plant matter (e.g. leaves, weeds), phytoplankton and invertebrates		Mid-water to bottom depths; seems to prefer standing water habitats instead of flowing waters; useful in cropping excessive vegetation in reservoirs	
Tilapia (*Oreochromis niloticus*), Cichlidae	Omnivorous grazer, e.g. phytoplankton, periphyton, aquatic plants, small invertebrates, benthic fauna, detritus, bacterial films associated with detritus; typical feeds: agricultural by-products, manures, compound feeds	Early sexual maturity in ponds; spawn with temperatures > 24°C; spawn throughout the year in tropics; sex-reversal is practiced to produce all-male populations	Tropical species; lethal temperatures 11-12°C or 42°C respectively (preferred range: 31-36°C); relatively resistant to poor water quality; over-reproduction in ponds; for complete harvest, seining plus draining required	Wide range of culture systems; Culture in ponds, floating cages, tanks, raceways, etc. Pond culture with a variety of inputs such as agricultural by-products, inorganic fertilizers and feed; polyculture with carp; production in monoculture with animal manures

BHC = Bighead carp; CC = Common carp; GC = Grass carp; MC = Mud carp; MRI = Mrigal; SB = Silver barb; SC = Silver carp; TIL = tilapia

2.3.2 Feeding characteristics and growth of the grass carp

Young grass carp are mainly carnivorous and feed on zooplankton (Trevisan, 1979; De Silva and Weerakoon, 1981), the spawn of common carp (Singh et al., 1976) as well as mosquito larvae (Singh et al., 1977). However, when they reach a certain size (> 36 mm; Opuszynski, 1972; > 25 mm, De Silva and Weerakoon, 1981), grass carp tend to change their feeding habits from carnivorous to herbivorous. Grass carp possess large, grooved pharyngeal (throat) teeth, which allow them to efficiently shred plant-derived material (Prowse, 1971; Sanders et al., 1991). They do not have stomachs, and their intestines, which are usually twice as long in length as the fish's body, are connected directly to the oesophagus (Trevisan, 1979).

In its early stage, grass carp usually consume filamentous algae and small species of flower-bearing plants, such as *Lemna* sp. The diet of the larger fish (> 250 g) consists of emergent plants, leaves and plant shoots (Opuszynski, 1972). The feeding and growth of the grass carp is strongly influenced by temperature (Opuszynski, 1972; Cai and Curtis, 1990; Osborne and Riddle, 1999) as well as fish weight (Osborne and Riddle, 1999). While no plants are consumed at temperatures below 12°C, intensive feeding occurs from temperatures of 20°C onwards (Opuszynski, 1972). Opuszynski (1972) reports that grass carp may consume over 100% of their body weight per day at temperatures between 22-33°C. At 27°C, the average food consumption of young grass carp fed duckweed (wet weight) is reported to be 89.8% body weight day^{-1} (Cui et al., 1992). Osborne and Riddle (1999) demonstrate that relative feeding rates also decline with an increase in fish size. Small grass carp (~ 0.3 kg) fed *Hydrilla* consume about 100%, fish of 1 kg 50% and fish of 3 kg only 30% of their respective body weights.

Adult grass carp are known to voraciously feed on aquatic plants, rendering grass carp as an efficient biological agent for aquatic weed control. This characterizes the typical use of this species in temperate climatic regions such as Europe and North America (Opuszynski, 1972; Osborne and Riddle, 1999). However, in Asia, grass carp make up an important food source and a common component in polyculture systems (Ling, 1977). In China, for example, grass carp are mainly fed plant material (Little and Muir, 1987; Cui et al., 1994); therefore, suitable feeds for grass carp are composed of soft and tender aquatic macrophytes as well as terrestrial plant parts, such as land grasses, outer layers of vegetables as well as leaves, for example, of sweet potatoes, legumes and cassava (Ling, 1977).

Terrestrial plants used in feeding trials with grass carp comprise cassava leaves (Tan, 1970), Napier grass (Tan, 1970; Venkatesh and Shetty, 1978a,b; Law, 1986; Shrestha and Yadav, 1998), *Cynodon dactylon* (Hajra, 1985; Hajra et al., 1987), carpet grass (Law, 1986), and ryegrass (Shireman et al., 1978). Compared to the use of terrestrial plants in feeding trials with grass carp, considerably more work has been undertaken in the testing of aquatic plants. These investigated plants include *Ceratophyllum demersum* (Venkatesh and Shetty, 1978a,b; Young et al., 1983; Hajra, 1987), *Hydrilla* (Tan, 1970; Shireman et al., 1978; Venkatesh and Shetty, 1978a,b; Cai and Curtis, 1989, 1990; Pine and Anderson, 1991; Osborne and Riddle, 1999), *Lemna ssp.* (Cassani et al., 1982; Carter and Brafield, 1991; Cui et al., 1992), *Spirodela polyrhiza* (Hajra and Tripathi, 1985; Hajra et al., 1987; Cui et al., 1992, 1994; Pipalova, 2003), *Wolffia columbiana* (Cassani et al., 1982), *Eichhornia crassipes* (Riechert and Trede, 1977), *Elodea densa* (Cai and Curtis, 1989, 1990), *Najas guadalupensis* (Young et al., 1983) and *Myriophyllum* sp. (Cai and Curtis, 1989, 1990). Selected results of these investigations are summarized in Table 3. The bulk of these experiments have been carried out under laboratory conditions. Tacon (1995), however, doubts that these studies possess much practical applicability for semi-intensive pond farming conditions.

Absorption efficiencies of plant-based diets are usually lower than those of animal-based diets; therefore, grass carp have to consume larger amounts of food in order to achieve a certain absorption rate (Cui et al., 1992). Due to fast and incomplete digestion, these fish produce high amounts of only partially digested waste, making grass carp an ideal candidate for fish polyculture (Ling, 1977; Shreshtha and Yadav, 1998).

Cui et al. (1994) found that grass carp can hardly digest crude fibre, which is in line with the statements of Lesel et al. (1986), who observed low cellulasic activity in general as well as a low abundance of cellulolytic flora in the intestines of grass carp. Recently, Saha et al. (2006) isolated strains in the intestines of grass carp that are capable of producing cellulolytic enzymes in varying quantities. However, the presence of cellulolytic bacteria alone does not automatically point to the ability of these fish to use cellulose (Saha et al., 2006). The inefficient assimilation of plants has also been attributed to the unusually short intestine length of the grass carp (see review of Federenko and Fraser, 1978).

Grass carp, however, are able to macerate plant cells with their pharyngeal teeth and thereby weaken or rupture the cell walls and access the cell contents. When grass carp were fed *Elodea*, small pieces of stems and leaves (0.5-10 mm long) of this plant were recovered from the intestines (Petridis, 1990). Petridis (1990) showed that some of these epidermal plant cells had lost their entire cytoplasmatic content.

The poorly digested excreta of the grass carp may serve as pond fertilizer or can be directly consumed by other fish (Ling, 1977; Prein, 2002) as well as by benthic invertebrates (Petridis, 1990). The isopod *Asellus aquaticus* showed higher growth rates when fed the faeces of *Elodea*-fed grass carp compared to fresh *Elodea*, which has been explained by a more efficient use of the pre-damaged tissues (Petridis, 1990). The faecal matter was observed to be rich in nutrients whenever grass carp were fed either terrestrial or aquatic plants (Venkatesh and Shetty, 1978a; Hajra et al., 1987). Other fish in the ponds may even further consume the microbes that flourish on the grass carp waste material (Wohlfarth and Schroeder, 1979). Also, intestinal microorganisms in the faeces probably attract other species in the system (Petridis, 1990). The grass carp has an intestinal flora that is one hundred times greater than that of the trout, for example. This has been explained by the anatomy of this species, which is stomachless, so microbes may enter into the intestines in greater numbers (Lesel et al., 1986).

By combining grass carp with filter-feeding fish, such as silver carp, the overall fish yields can be increased (Ling, 1977; Huazhu and Baotong, 1989; Shreshtha and Yadav, 1998). Huazhu and Baoton (1989) stated that through the stimulation of natural food production caused by the grass carp faeces, three silver carp can be grown in the presence of one grass carp. In addition, the maintenance of desirable water quality is easier in grass carp polyculture compared to grass carp monoculture ponds (Huazhu and Baotong, 1989; Shreshtha and Yadav, 1998). When grass carp were fed duckweed (*Spirodela polyrhiza*) in tanks, the biomass of phytoplankton increased with fish stocking densities (Pipalova, 2003).

Table 3: Body weight gain, specific growth rate and food conversion ratio in selected feeding experiments carried out with grass carp

Feed	Days[1]	T (°C)	Initial BW (g)	BWG* (g)	SGR* (%)	FCR	Author(s)
Terrestrial plants							
Cassava leaves	168	n.r.	311.3	397.6	0.49	n.r.	Tan, 1970
Cynodon dactylon	15	20-23	13.6	1.8	0.81	3.3	Hajra, 1985
C. dactylon	15	20-23	50.2	3.2	0.41	3.3	Hajra, 1985
Napier grass	168	n.r.	290.6	1 271.7	1.00	n.r.	Tan, 1970
Napier grass	97	24-34	9.8	119.1	2.66	n.r.	Shrestha and Yadav, 1998
Hybrid Napier grass	182	~ 28	12.0	313.1	1.81	4.6	Venkatesh and Shetty, 1978b
Ryegrass (pellets)	68	~ 25	2.8	3.7	1.24	12.8	Shireman et al., 1978
Ryegrass (pellets)	68	~ 25	34.7	5.4	0.21	24.0	Shireman et al., 1978
Aquatic plants							
Ceratophyllum demersum	182	~ 28	12.0	53.9	0.94	10.3	Venkatesh and Shetty, 1978b
C. demersum	30	20-23	52.2	1.691	0.11	4.1	Hajra, 1987
Hydrilla	168	n.r.	336.6	1 663.4	1.06	n.r.	Tan, 1970
Hydrilla	182	~ 28	12.0	88.6	1.17	9.4	Venkatesh and Shetty, 1978b
Lemna minima	68	~ 25	2.8	36.5	3.88	1.6	Shireman et al., 1978
L. minima	68	~ 25	34.7	78.3	1.74	2.7	Shireman et al., 1978
Spirodela polyrhiza	30	20-23	51.6	3.8	0.24	3.1	Hajra and Tripathi, 1985
S. polyrhiza	30	20-23	14.2	2.1	0.46	3.2	Hajra and Tripathi, 1985
S. polyrhiza	14	~ 21	19.6	2.0	0.70	2.0	Pipalova, 2003
L. minor/S. polyrhiza	21	~ 27	3.8	n.r.	1.77	n.r.	Cui et al., 1992

[1]Duration of experiment (in days)
T = Water temperature; BW = Body weight; BWG = Body weight gain = Final body weight - initial body weight; SGR = Specific growth rate = (ln final body weight (g) – ln initial body weight (g))/time (days) x 100; FCR = Food conversion ratio = feed applied (DM)/live weight gain
n.r. = not reported; *partly calculated from the published data

2.3.3 Carp production systems

Carp production techniques are highly diversified, ranging from extensive (e.g. pond without fertilization or supplemental feeding) to highly intensive systems (e.g. cage culture). Carp are cultured in temperate as well as tropical conditions, in monoculture or polyculture, as stand-alone enterprise or integrated with other agricultural activities (Kestemont, 1995).

Criteria for classifying an aquaculture system according to its intensity are given by Edwards et al. (1988) on the basis of feeding practices:

a) Extensive systems, in which only natural food is utilized without intentional pond inputs
b) Semi-intensive systems, which rely on fertilization to produce natural food and/or supplementary feed. Here, a significant amount of the fish diet is supplied with natural feed
c) Intensive systems, in which fish receive a nutritionally complete pellet feed with little or no nutritional benefits from natural food produced in the pond.

Compared with the description provided by Edwards et al. (1988), Appledorf et al. (2003) include pond systems with limited inputs (e.g. animal and plant wastes) to extensive systems. Edwards et al. (1988) subdivide semi-intensive systems into those with low quality manure and/or macrophytes as supplementary feed and more productive ones with high quality manure and/or pellets and aeration (see Figure 5). Semi-intensive fish production dominates tropical aquaculture (Beveridge and Haylor, 1998).

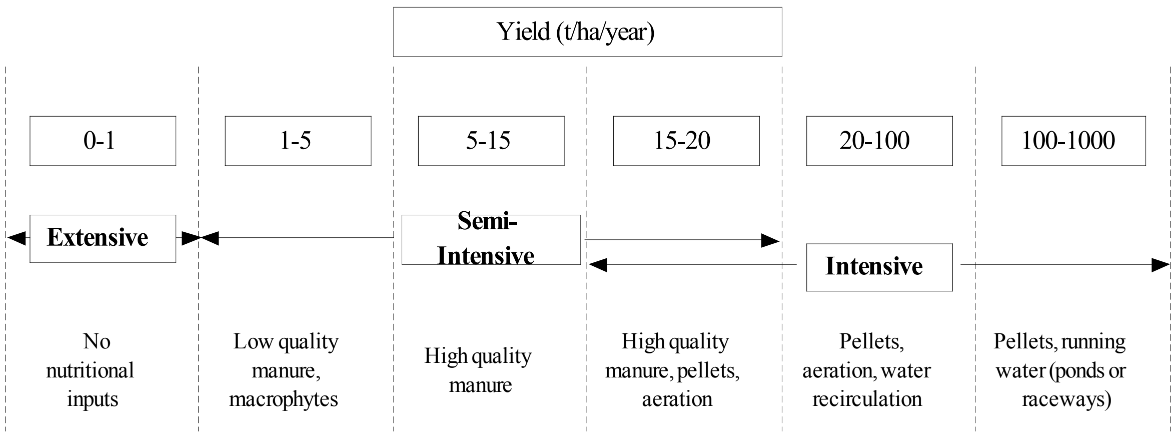


Figure 5: Intensification of aquaculture systems (redrawn from Edwards et al., 1988)

Table 4 lists some common culture methods in temperate and tropical regions. Carp polyculture is the typical practice in Asia (Ayyapan, 2001a; De Silva, 2003a).

Table 4: Carp culture methods (source: review of Kestemont, 1995)

Culture method	Specifications and examples
Extensive common carp monoculture production in earthen ponds	e.g. common carp in earthen ponds in Western Europe
Intensive monoculture	Net cage culture Farm or irrigation pond culture Running water ponds and raceways
Integrated carp monoculture	e.g. integrated rice-carp culture
Carp polyculture and integrated fish farming	Diverse fish species

2.4 Polyculture with carp as major species

Polyculture systems have been in use for centuries (Naylor et al., 2000) and are thought to have originated in China (De Silva, 2003a). In a polyculture system, different fish species occupying different trophic and spatial niches are produced together in order to optimally use available pond resources. Through positive interactions, fish yields and growth of each species can be higher in polyculture in comparison to monoculture systems (Milstein, 1992; Kestemont, 1995; De Silva, 2003a). Ayyapan (2001a) defines polyculture as "a strategy to utilize the different food niches in an aquatic system and harness maximum possible amounts of nutrients and energy in the form of fish". The key players in these systems are producers, consumers and decomposers. Primary producers synthesize organic matter by taking in inorganic nutrients and utilizing solar radiation and serve as feed for zooplankters (primary consumer level). Likewise, zooplankters are preyed upon by consumers of higher trophic levels. Decomposers also play an important role since they degrade organic matter into simple compounds, which can then be mineralized, and the detritus can be consumed by fish (e.g. Ayyapan, 2001a).

The choice of species, size and number of fish to be stocked as well as the time of stocking in polyculture systems depends on the following factors: quantity and quality of each type of potential food available in the pond, the extent to which production of each of these groups can be increased, i.e. with the application of fertilizers, the growth rates and replenishment (Ling, 1977; Milstein, 1992). Not all carp species can be cultured together. Compatibility depends on the feeding behaviour and habitats within the pond system among other factors. For example, silver carp filter phytoplankton, while grass carp are macroherbivorous, and both fish species mainly occupy the upper layers of the water column. However, mrigal are bottom feeders and are therefore mainly found in the lower layers near the sediment. Common carp are omnivorous fish and generally feed on detritus (e.g. Ayyapan, 2001a; FAO, 2006b). Cichlid tilapia have also been grown in combination with carp in Asian polyculture systems (Suresh, 2003). Figure 6 illustrates the feeding habits of fish typically found in a Chinese polyculture system.

Polyculture systems can by intensified through fertilization (e.g. animal manure, urea, super-phosphate) and supplementary feeding. De Silva (2003a) describes a carp polyculture system in India, where Chinese and Indian carp were stocked at a density of 5 000 ha^{-1}, ponds were fertilized and fish were supplemented with simple feeds, such as a mixture of rice bran and oil cake. In these ponds, yields of 9 tons ha^{-1} year^{-1} were harvested. Yields of different carp species cultured in Andhra Pradesh (India) range from 5 300-14 620 kg ha^{-1} (De Silva, 2003a).

Carp polyculture systems can also be integrated into the overall farming system (e.g. Ling, 1977; Sinha, 1985; Ayyapan, 2001a; De Silva, 2003a).

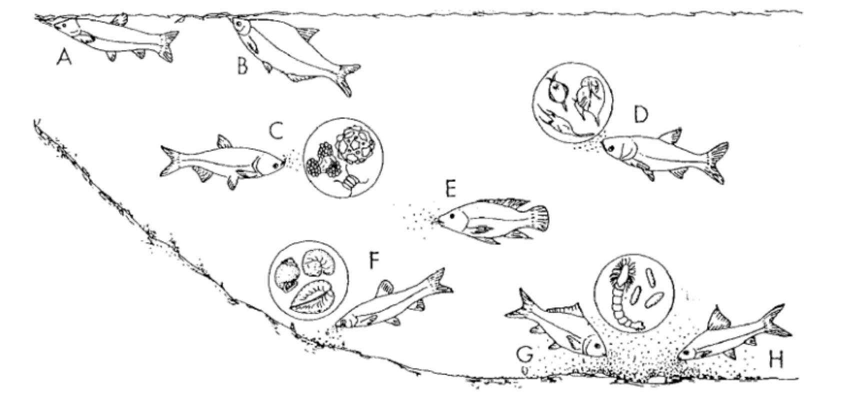


Figure 6: Natural food resources utilized by major fish species cultivated in Chinese polyculture ponds
Grass carp (A) and wuchang fish (B) feed on land grasses and aquatic macrophytes; silver carp (C) graze on phytoplankton, bighead carp (D) consume zooplankton, tilapia (E) feed on both types of plankton, green fodder and benthic organic matter; black carp (F) eat molluscs and common carp (G) and mud carp (H) consume benthic invertebrates and bottom detritus (Zweig quoted in Tacon and De Silva, 1997)

2.5 Integrated agriculture-aquaculture systems

Edwards et al. (1988) define integrated farming systems as “an output from one subsystem … which otherwise may have been wasted becomes an input to another subsystem resulting in a greater efficiency of output of desired products from the land/water area under a farmer’s control. There is synergism in integrated farming since the working together of the subsystems has a greater total effect than the sum of their individual effects”. Major features of these systems include by-product recycling and improved space utilization. In 1998, Edwards redefined and broadened the definition of integrated farming, which includes aquaculture as the “concurrent or sequential linkages between two or more human activity systems (one or more of which is aquaculture), directly on-site, or indirectly through off-side needs and opportunities, or both” (Edwards, 1998). The latter and more flexible definition includes off-farm activities as well as off-farm inputs (e.g. commercial inorganic fertilizers) as being a part of integrated farming systems. Lightfoot et al. (1993), Pullin and Prein (1995) and Pullin (1998) propose an even broader perspective, which encompasses the fully integrated management of all natural resources available to farm households. Lightfoot et al. (1993) suggests the use of the term “Integrated Resources Management” instead of integrated farming.

In addition to being able to increase productivity per unit of land or water, integrated farming including aquaculture has many other benefits. Reliance on inter-farm or agro-industrial inputs is decreased, risks are spread out as a result of diversification and the provision of a more balanced diet for farming families can be sustained (Edwards et al., 1988; Edwards and Little, 1995; Devendra, 1997; Edwards, 1998; Prein, 2002). Compared to integrated aquaculture systems, stand-alone enterprises often focus on high-value species for export purposes, which are usually considered capital intensive and risky ventures. This is therefore not an option for resource-poor farmers, who usually demonstrate risk-adverse attitudes (Lightfoot et al., 1993; Prein, 2002). Additionally, aquaculture stand-alone enterprises are often associated with negative effects such as pollution and destruction of natural habitats as well as a reliance on fishmeal (Naylor et al., 2000). In contrast, integrated systems with efficient use of water and nutrients are usually considered to be environmentally sound activities (e.g. Appleford et al., 2003). The culturing of fish in integrated agriculture-aquaculture (IAA) systems has been recommended as a tool that can alleviate poverty and promote sustainable livelihoods (Prein, 2002).

Several types of IAA systems are practiced in Asian countries (see review of Prein, 2002) and have a long tradition in the Red River Delta of Northern Vietnam (Edwards and Little, 1995); however, it is generally assumed that the concept of integrated farming originates from China (e.g. Edwards et al., 1988; Pullin and Prein, 1995). Ponds offer a relatively high potential for integration on farms (Prein, 2002); wastes may flow to and from the pond, for example, in the form of vegetable gardening on the pond banks where pond water and mud are used for irrigation and fertilization. Likewise, crop residues are either used as pond fertilizer or fish feed (Ling, 1977). Examples of possible interactions between subsystems in a crop-livestock-fish integrated farming system are shown in Figure 7. In general, IAA systems are operated over the entire spectrum of scales, from production for the main purpose of subsistence to fully market-oriented operations (Prein, 2002).

IAA can be found in rather simple systems, where either crops or animals are linked to fish or multi-component integrated systems that exhibit more than three components and the use of off-farm inputs (Little and Muir, 1987). Prein (2002) suggests classifying the diverse systems according to input sources instead of linkages. He distinguishes between systems that are either plant- or animal-based and systems integrated into other operations. In systems where plants operate as the major pond inputs, aquatic or terrestrial plants that are derived from native, forage or cultivated crops usually serve either as green manure or directly as fish feed. Herbivorous fish in a polyculture system, such as grass carp, can process raw plant material and provide its poorly digested excreta to the pond system as fertilizer. Systems based on animal manure and offal as major inputs can be subdivided into non-livestock- and livestock-based systems. Non-livestock input sources include the application of human faeces or the droppings and waste pupae of silkworms. However, in the case of livestock-based systems, the manure from farm animals and, in some cases, slaughterhouse wastes are usually applied to fishponds. Several examples of the integration of aquaculture into other operations include the production of fish in rice-fields or in mangroves.

Organic fertilizers, either derived from plants or animals, are often key elements in IAA systems since they promote natural food production in the ponds, e.g. through the production of phytoplankton, zooplankton, benthic organisms and detritus (see review of Prein, 2002).

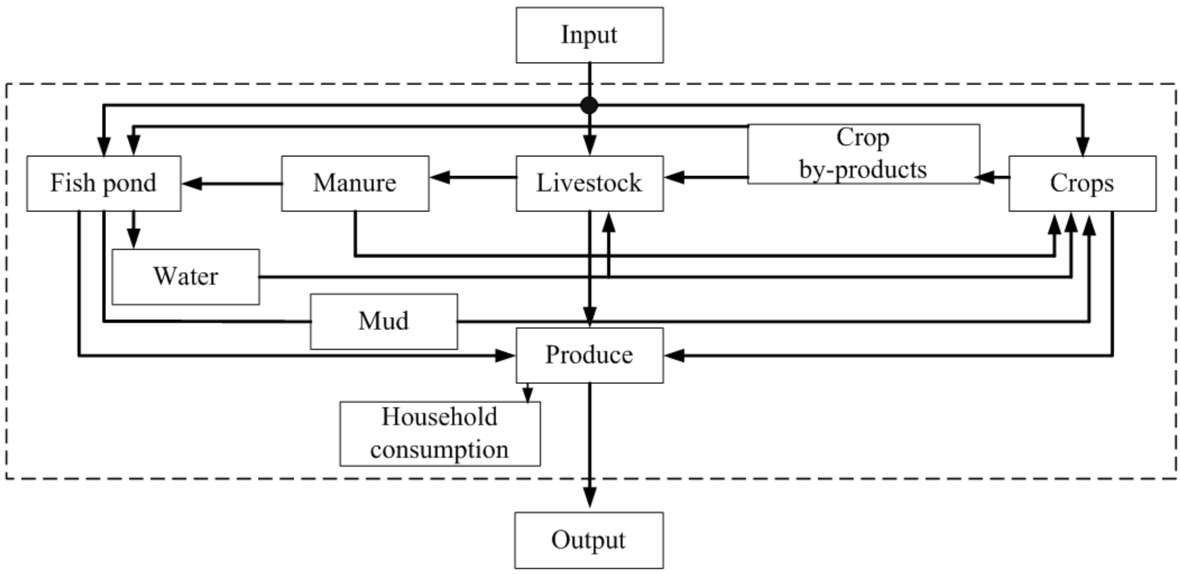


Figure 7: Possible interactions between the various subsystems in a crop-livestock-fish integrated farming system; the dashed line represents the farm boundary (Figure redrawn and modified from Edwards et al., 1988 and Edwards, 1998)

2.5.1 The use of manure in ponds

The use of manure in conjunction with the polyculture of Chinese cyprinids has a long tradition in China (Wohlfarth and Schroeder, 1979; Wohlfarth and Hulata, 1987). A number of reports have been published concerning the integration of livestock and fish production.

For example, fish are grown in ponds supplied with droppings from ducks (Barash et al., 1982; Edwards, 1983; Man, 1992), chicken (Duan et al., 1998; Milstein et al., 1991), pigs (Malecha et al., 1981; Zhu et al., 1990; Zoccarato et al., 1995; Dhawan and Kaur, 2002), cattle (Moav et al., 1977; Barash and Schroeder, 1984) and buffalo (Edwards et al., 1994a,b; Shevgoor et al., 1994). Also, the integration of fish with other animals like silkworms (Ling, 1977) as well as sheep (Prinsloo and Schoonbee, 1987) has been reported. Manure is applied to polyculture ponds typically comprising fish species, such as silver carp, common carp and tilapia (Moav et al., 1977; Malecha et al., 1981; Wohlfarth and Hulata, 1987; Zhu et al., 1990; Milstein et al., 1991). However, manure is also applied to fish (e.g. tilapia) produced in monoculture ponds (Edwards et al., 1994a,b). Fish yields from manure-fed fishponds ranged from 7 to 36 kg ha^{-1} day^{-1} in different investigations that were summarized by Wohlfarth and Hulata (1987).

Livestock may be housed over the water body or chicken coops or pigsties are constructed along pond banks. Both variants lead to a continuous addition of fresh manure to the pond. In China, in the most prevalent aquaculture system, manure is transported to the ponds without the integration of livestock and aquaculture units (Wohlfarth and Hulata, 1987). In the fishpond, manure is directly consumed by fish or serves for the production of food organisms (Ling, 1977; Wohlfarth and Schroeder, 1979; Wohlfarth and Hulata, 1987). Intensive manuring stimulates the generation of phytoplankton, zooplankton and benthic organisms (Wohlfarth and Hulata, 1987). Also, the microorganisms that may flourish on manure are consumed by certain fish species (Wohlfarth and Schroeder, 1979).

Manure varies in nutrient content corresponding to animal species, type, age, mode of storage and form of application (Sevilleja et al., 2001; review of Prein, 2002). Generally, ruminant manure is considered less effective as a pond input (Prinsloo and Schoonbee, 1987; Edwards et al., 1994a,b), while poultry manure is a rather high quality input to fishponds (Edwards, 1983; Edwards et. al, 1996b). In Thailand, extrapolated annual fish yields of 8.73 tons ha^{-1} were obtained when 1 335 ducks were integrated with fishponds. The high yields obtained from the duck integration have been primarily attributed to phytoplankton growth promoted by the soluble nutrients derived from the duck droppings. This provided protein-rich feed for the filter-feeding tilapia that were used in these studies (Edwards et. al, 1996b). Assuming that fish production is proportional to the nitrogen (N) content of manure, hypothetically, 85 buffalos, 205 pigs (410 pigs $year^{-1}$) or 40 dairy cows would be required to produce equivalent fish amounts (Edwards, 1983).

Edwards et al. (1996b) state that buffalo manure serves as a relatively poor nutritional input for ponds, since it contains low contents of N (only 1.4% as compared to 4.4% of dry matter (DM) in duck manure) as well as low phosphorous (P) contents (0.2% of DM as compared to 1.1% of DM in duck manure), which requires relatively high DM loading rates in order to apply similar N amounts. High dry matter loading rates cause a high oxygen demand, which can also potentially affect fish growth. While duck manure enhances phytoplankton growth, it is inhibited by the application of buffalo manure. This is caused by low soluble N and P inputs through buffalo manure and marked reduction of light penetration into the water column since this manure stains pond water dark brown due to the release of tannins and flavonoids (Edwards et al., 1994a,b; Shevgoor et al., 1994).

In China, net fish yields averaged 10.2 kg ha^{-1} day^{-1}, when low density (0.6-0.7 fish per m^{-2}) planktophagous and benthophagous carp polyculture ponds were supplied with 31-48 kg DM ha^{-1} day^{-1} of pig manure. The yields were proportional to the amount of manure applied (Zhu et al., 1990).

2.5.2 Practical examples for integrated agriculture-aquaculture (IAA) systems in Vietnam and neighbouring countries

Several systems of IAA are found in Asia, where aquaculture is integrated in other farming activities. Either ponds receive nutrient inputs from other on- or off-farm sources or fish culture is physically integrated into other enterprises, such as the integration of fish production in paddy fields (Prein, 2002).

Since the early 1980s, the use of land in the form of VAC systems has been widely promoted in Vietnam in order to increase and stabilize the nutritional standard of the rural poor (Vacvina, 1995; Luu, 2001b; Hop, 2003). The Vietnamese acronym “VAC system” stands for the integration of garden (*vườn*), pond (*ao*) and livestock pens (*chuồng*). This system is practiced in most regions of Vietnam (Vacvina, 1995), such as irrigated lowlands, rainfed uplands and peri-urban areas. Also, in the province of Son La, this form of IAA is widely employed (Rake et al., 1994; Luu, 2001b). Diverse modifications of the original VAC model can be found across the different ecological regions (Vacvina, 1995; Luu, 2001b, Luu et al., 2002; Hop, 2003). The promotion of VAC systems in Vietnam has been considered very successful and has been established as an effective solution for the alleviation of poverty, improvement of diets and prevention of malnutrition (Hop, 2003).

Luu (2001b) describes the upland VAC system, also located in the Son La province. Ponds with sizes ranging between 100 and 1 500 m² are constructed close to houses, livestock pens and gardens. Typically, 20-25% silver carp, 5-10% grass carp, 5-10% common carp, 20-30% rohu and 20-30% mrigal are stocked and domestic and kitchen wastes as well as livestock manure are provided at rates of 0.05-0.15 kg m^{-2} twice monthly. Three months after stocking, farmers start to continuously harvest a total of approximately 1 to 1.2 tons of fish per hectare and year. In this system, pond mud is used as a fertilizer for fruit trees.

Considerable variations in the aquaculture productivity between different agro-ecological zones have been described from the Red River Delta in Vietnam, with yields ranging between 50 kg to over 6 tons with an average of 2.5 tons per hectare in a 9-month production season (Luu et al., 2002). Carp are raised in polyculture systems with rohu and silver carp ranking first, mainly fed on grass, pig manure and rice bran. After implementation of some modifications such as improvements in stocking and harvesting techniques (e.g. stocking of larger-sized fingerlings, reduction of stocking density and changes in fish composition in favour of grass carp) and improvements in feed supply (e.g. substitution of rice bran with grass and manure and application of modest amounts of inorganic fertilizers), mean yields could be doubled after a 3-year project period. However, some constraints still have to be addressed such as the increased occurrence of Red Spot Disease in grass carp, which has been attributed to the intensification of fish production (Luu et al., 2002).

In the Mekong delta of Southern Vietnam, seven different VAC systems are commonly practiced in different stages of intensification; these comprise fruit orchards, ponds and pigs or poultry (Nhan et al., 2005). Low yields are caused by mismatches in the complex multi-enterprise production system and low-nutrient density in the supplied on-farm inputs. The authors state that yields could probably be improved with the application of off-farm inputs, such as by-products from the agro-processing industries.

Dien and Quynh (2001) describe an aquaculture system introduced in Vietnamese upland areas, which is characterized by stream-fed flow-through ponds. Here, mostly cyprinids and tilapia are produced with stocking rates of 65% grass carp, 15% mrigal, 5% silver carp, 10% common carp and 5% tilapia. Dien and Quynh (2001) classify this system as semi-intensive, referring to the high stocking densities (e.g. 2-3 fish m^{-2}) and frequent water exchange (1/4 to 1/3 of pond volume daily). They consider the water environment in this system as being favourable since it inhibits reduced dissolved oxygen levels (DO) and waste accumulation. They state that during the rainy seasons, pond water can become contaminated with sediments and waste from the catchments area resulting in turbid water and Red Spot Disease in grass carp. Fish are fed twice daily at rates of approximately 25-50% of their total body weight; feed can consist of maize, cassava, banana or native plant leaves, cassava tuber, banana trunk, sweet potato and duckweed. Yields range between 3 to 5 tons ha^{-1} $year^{-1}$ and harvesting sizes are 2-3 kg for grass carp, 0.4 to 0.8 kg for mrigal and common carp, 0.7 to 1.5 kg for silver carp and 0.15 to 0.25 kg for tilapia (Dien and Quynh, 2001).

Yang et al. (2001) report fish yields of up to 6 tons ha^{-1} $year^{-1}$ in integrated grass-fish farming systems in China, where fish (commonly cultured species include grass carp, silver carp, bighead carp and common carp) are either fed on cultivated grass or water hyacinth without supplemental feeding or the use of additional manure.

3 Material and methods

Figure 8 shows the data collection during the study period on the macro, meso and micro levels. On the macro level, different techniques were applied for data collection, whereas data on the meso level was predominantly collected through interviews and the micro level relied mainly on measurements from selected ponds ("case study ponds").

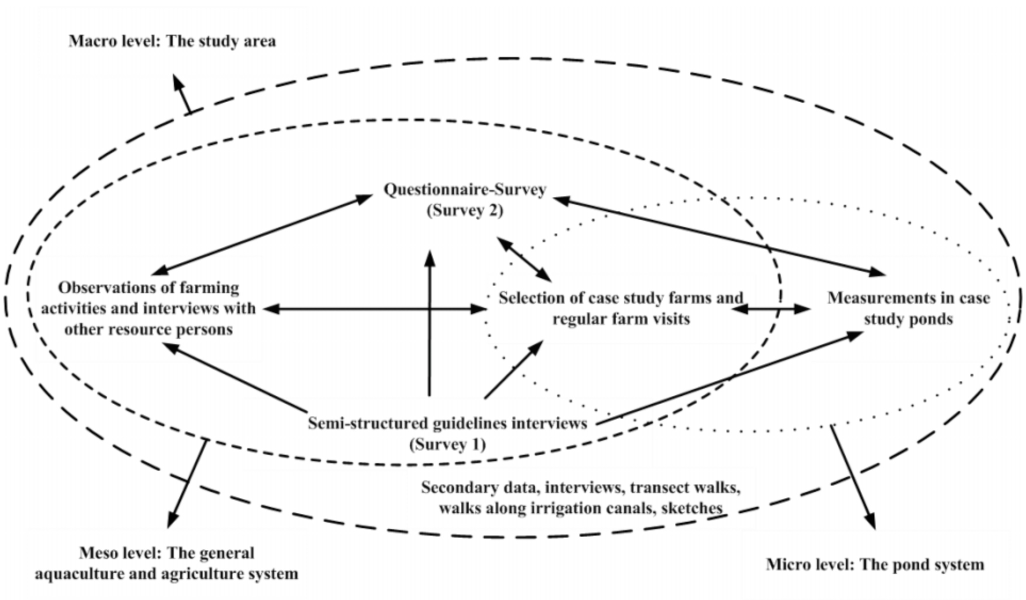


Figure 8: Data collection and information flow during the study period

3.1 The study area and its general description (macro level)

3.1.1 Location of the study area

The study area is located in Yen Chau district (Son La province) approximately 300 km from Vietnam's capital city of Hanoi and 60 km from the provincial capital of Son La. Yen Chau is located next to road no. 6, which connects Hanoi with Son La; the road was under construction during the study period.

The majority of the research was carried out in three communes around Yen Chau town: Chieng Khoi, Sap Vat and Vieng Lan. Only during the initial survey (survey 1), also six farmers in the Chieng Sang commune were interviewed. Figure 9 shows the location of these communes in Yen Chau district.

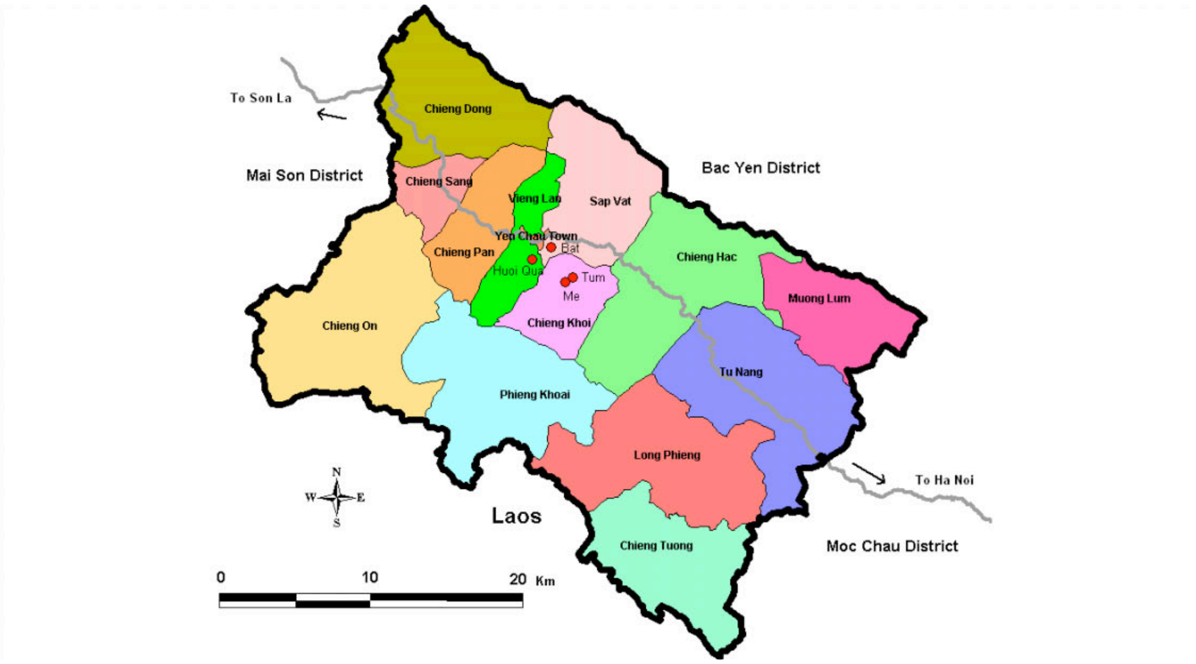


Figure 9: Map of Yen Chau district with the location of the villages of the case study farms (source: The Uplands Program (unpublished), modified)

3.1.2 Collection of secondary data

Secondary data was gathered from the Statistical Office in Yen Chau and from the People's Committees at the district (Yen Chau) and communal (Chieng Khoi, Sap Vat and Vieng Lan) levels. Data concerning the local climate was obtained from the Yen Chau Meteorological Office.

3.1.3 Interviews with local authorities

Staff members from 3 communal People's Committees as well as 22 village headmen were interviewed regarding general information about the communes and villages, respectively. The headmen were questioned regarding the typical agriculture and pond systems, the percentage of village households involved in fish production and the relative importance of different farm products as either subsistence or cash crops for the villagers.

3.1.4 Transect walks and walks along the irrigation canals with key individuals

Transect walks or walks along irrigation canals were undertaken with local key individuals, such as elderly people, in order to gain a better understanding of the land use and irrigation system in the study area. During these walks, the local people were interviewed about the area visited.

3.1.5 Sketches of the study area

Sketches were created in order to illustrate the land use as well as the irrigation system in the various communes. In addition, these sketches show the location of the case study ponds (micro level). Points were collected using GPS (Global Positioning System, Garmin, GPS 12 XL) at distances of every 50 meters or in the case of curvy roads, every 20 meters. Also, altitudes of the investigated ponds and villages were determined through the collection of GPS points. The GPS points were entered into MapInfo (6.0) and afterwards, the ID was linked to the software ArcView (3.1a).

3.2 Interview-based survey on the common aquaculture and agriculture system (meso level)

3.2.1 Semi-structured interviews (Survey 1)

From January to April 2004, a total of 70 fish farmers belonging to the ethnic Black Thai minority from villages of three different communes were consulted (Chieng Khoi: Na Dong, Hiem, Me, Tum; Sap Vat: Dong, Bat, Khoong, Khin, Na Pa; Chieng Sang: Bung Mo, Mai Ngap). The farmers were queried about their pond and farming systems by using semi-structured interview guidelines and with the help of Vietnamese interpreters. The main purpose was to gain a general understanding of the aquaculture system as well as to aid in the selection of case study farms. The villages were selected based on the advice of the local extension service; the choice of farmers was made by the village headmen. They were requested to choose those fish farmers, who they considered to be “typical”.

The interview guidelines comprised questions concerning the ponds themselves, their management (pond size, water flow, water source, etc.), fish stocks (fish species, stocking size, fish quantities, source, prices, etc.), feeding and manure regime (types of feed and manure, frequency of manure application, etc.), harvests and yields (time of harvesting, harvesting techniques, quantities and value of fish harvested, household consumption of fish, etc.), access to off-farm inputs as well as knowledge of fish farming techniques. In addition, farmers were asked about other farm-related and off-farm activities. After each individual interview, visits to the pond sites were undertaken.

After the interviews, a report was written about each observed farmer based on the outcome of the interview itself as well as additional information, including special observations or occurrences and the accessibility of the village and pond. Photos of the farmers and the ponds supplemented these reports. The additional information was collected in order to serve as a decision base for the selection of the case study farms.

3.2.2 Selection of the case study farms and regular farm visits

In total, nine case study farms were selected for an in-depth study. They were visited monthly and the farmers were interviewed about current farm and pond activities. This type of data is considered in the meso part of the investigation, while measurement data from the investigated ponds is presented in the micro part.

The selection of the farms were dependent on whether the ponds were operated in a "typical" manner for the region, the willingness of the farmers to cooperate with the study, their compliance with catching fish in the initial part of the study as well as the accessibility of the pond. Also, a high skill level in the Vietnamese language was a pre-condition for the selection of farmers on the basis of cooperation. Finally, the farmers were selected in a relatively subjective manner. The predictability of long-term cooperation was assessed according to the farmers' interest in fish production and research.

In total, twelve farmers were selected and contacted a second time. In the end, three farms on a mid-level plateau (CK1, CK2, CK3 from Chieng Khoi) and three farms in the valley (SV1, SV2, SV3 from Sap Vat) were selected. The cooperative work with these farms began between May and August 2004. In all six cases, the investigated ponds were located in places that could either be classified as residential or paddy field areas. In June 2005, three more farmers were selected for participation in cooperative work (VL1, VL2, VL3 from Vieng Lan); the selection criteria were the same as in the case of the first six farmers. The ponds of these farmers were situated in the so-called "upland field area". In the following sections, fields situated on hillsides are referred to as "upland fields" even though they are sometimes located in lower altitudes compared to the paddy fields. Codes and locations of the case study farms and ponds as well as the duration of cooperative work are presented in Table 5. The location of the villages within the Yen Chau district can be observed in Figure 9.

During monthly visits, farmers were asked about their current pond and farm activities. Previously defined questions were used as a framework in these interviews, but personal observations of the ponds and farms were the main focus of these surveys. While the data gathered from all nine case study farms are considered in the meso part, measurement data (micro part) was only analysed in the cases of two farms per commune.

Table 5: Location of ponds of case study farms (case study ponds) and duration of cooperative work

CSF/ CSP	Commune	Village	CSP location	Walking distance[1]	Micro level[2]	Cooperation period (in months)
CK1	Chieng Khoi	Tum	Mid-level	0	X	15.05.04 – 21.05.06 (~ 24)
CK2	Chieng Khoi	Me	Mid-level	0	X	15.07.04 – 22.05.06 (~ 22)
CK3	Chieng Khoi	Me	Mid-level	0		16.01.05 – 21.05.06 (~ 16)
SV1	Sap Vat	Bat	Valley	0	X	07.07.04 – 17.05.06 (~ 22)
SV2	Sap Vat	Bat	Valley	4	X	29.07.04 – 20.05.06 (~ 22)
SV3	Sap Vat	Bat	Valley	0		16.08.04 – 18.05.06 (~ 21)
VL1	Vieng Lan	Huai Qua	Uplands	18	X	22.08.05 – 04.06.06 (~ 9.5)
VL2	Vieng Lan	Huai Qua	Uplands	18	X	27.10.05 – 05.06.06 (~ 7.5)
VL3	Vieng Lan	Huai Qua	Uplands	22		17.06.05 – 03.06.06 (~ 11.5)

CSF = Case study farm; CSP = Case study pond
[1]Proximate time required for walking from farmers' house to the case study pond (in minutes)
[2]The data of these case study farms were also analysed on the micro level

3.2.3 Questionnaire survey (Survey 2)

A detailed questionnaire with closed as well as open questions was developed and 85 farmers in the study area were interviewed between May and October 2005. This was done in order to quantify the information collected from the initial interviews on a broader and more standardized level. Based on the 22 interviews with village headmen (see 3.1.3), 15 villages from the studied communes were identified where fish is produced by more than half of the farmers' households. Out of these, seven villages (Sap Vat: Kha; Chieng Khoi: Me, Ngoang, Hiem; Vieng Lan: Kho Vang, Huoi He, Huai Qua) were randomly selected to take part in the questionnaire survey. The headmen of these villages provided lists of all available fish farmers; 15% of these farmers were randomly selected from each village. All interviewed farmers belonged to the ethnic Black Thai minority.

The farmer questionnaire was divided into the following sections: general information about the household, general farm information, general pond description and the use of water, fish species cultured, feed management, manure regime, harvests and yields, pond inputs, fish diseases and constraints in fish production (see appendix). The interviews were carried out with the help of two trained Vietnamese interviewers and each questionnaire took about one hour per household to complete.

3.2.4 Observations of farming activities and interviews with other resource persons

Besides the farmers who were interviewed in a formal manner, other farmers were contacted and interviewed in order to collect more information regarding the questions that came up during the study period. For example, these questions concerned farmers who sprayed pesticides, fed certain feed, observed fish diseases in their ponds, etc. Semi-structured interviews with a guideline were conducted with operators of the hatcheries in Son La and Yen Chau, local wholesalers and retailers of agricultural inputs, fish traders from the district and different communes, the Integrated Pest Management (IPM) department as well as the local extension service of Yen Chau. The information gathered from the formal interviews is supplemented by informal information collected from the market and queried fish traders regarding the current fish prices and fish sources. Usually, the Vietnamese staff obtained these prices in order to avoid biased answers in the case of foreigners' inquiries. Two related surveys complement this data.

3.2.5 Related survey: Grass carp diseases and other problems in aquaculture

In June 2004, a two-day workshop on grass carp disease and aquaculture was organized in Yen Chau, aiming at providing a platform for dialogue between farmers, extension workers and researchers in order to discuss problems of local fish production systems. In total, 40 people participated in the workshop; among them were farmers, extension staff and a staff member of the local veterinary service. Topics of discussion included the aquaculture system and related general problems, diseases affecting fish in the study area, possible causes, treatments and prevention measures. A summary of the minutes as well as photos from the workshop can be found in the appendix.

In total, 15 farms and ponds were visited during the occurrence of grass carp disease so that farmers could be interviewed about related topics, e.g. about the current feed use. Whenever possible, affected fish were weighed and examined for apparent disease-related symptoms and the water parameters of the pond were recorded (for methods, see 3.3.4).

3.2.6 Related survey: Pesticides

After observing grass carp mortalities in the study area, a special survey was carried out in order to describe the systems of “paddy field” and “fish pond” along with their interrelations. The aim of this study was to evaluate whether pesticides might have contributed to the fish mortalities in the ponds and to record the farmers’ perceptions on this issue.

From April to August 2005, wholesalers and retailers of agricultural inputs as well as fish and rice farming households in the villages Bat (Sap Vat), Dong (Sap Vat) and Huai Qua (Vieng Lan) were interviewed. From each village, ten households were randomly selected based on lists of residents provided by the village headmen. Farmers were surveyed using resource flow diagrams; on these, farmers recorded all inputs and outputs of the "rice" and "fish" systems and noted all interlinkages. Potential problems (e.g. introduction of pesticides into ponds) were discussed on the basis of these diagrams.

In addition to the interviews, duckweed samples from a paddy field were first collected prior to the application of the insecticide fenobucarb by a local farmer and then 12 and 24 hours respectively after the application of this pesticide. The samples were taken from a defined site; they were then deep-frozen and brought to the Plant Protection Department in Hanoi for analysis of the fenobucarb concentration in the different samples.

3.2.7 Presentation of data

For qualitative data, all interviews and observations are taken into account. For quantitative data, if it is otherwise not explicitly mentioned, the 155 interview responses from surveys 1 and 2 are considered and presented as averages.

3.3 Measurement-based survey of the pond system (micro level)

It has already been mentioned that the case study farms were visited monthly for the purpose of interviewing the farmers and observing the current farming activities. Of the nine selected farms, only six farms are taken into account on the micro level due to discrepancies between recorded and actual fish stocks as well as incomplete reporting of pond operation.

3.3.1 The "Farmer's Record Book"

During the entire period of cooperative work, the farmers were requested to weigh fish, feed and manure and create a daily record of all activities related to their pond (e.g. fish transfers, feed and manure application, labour input) in a record book. For this purpose, they were trained beforehand, supplied with the required equipment (book, balance and buckets) and compensated financially for their additional efforts. An example of a filled-out sheet of the farmer's record book is shown in Figure 10. Usually one household member was in charge of maintaining the book; in the following text, these farmers are referred to as "cooperating farmers". A Vietnamese staff member regularly visited the farms in order to check the quality of the records. The books were collected during the monthly farm visits and the records discussed with the cooperating farmers.

3.3.2 The general pond description

Sketches have been created to show the position of the ponds within their surroundings. In addition to the use of GPS points (see 3.1.5), the ponds were measured manually in order to minimize a lack of precision caused by potential error of the GPS. From this data, the accurate pond sizes were determined. For the determination of the pond depth, an iron pole was placed at a defined spot in the pond and the depths were measured monthly. The average depth over a year was determined and used in further calculations.

3.3.3 Sites of research and transportation of samples

For the description of the pond system, investigations were carried out at the farm, pond site and in laboratories. A field laboratory was established in Yen Chau town in order to process and store samples and dissect fish. Transportation of the samples from the ponds to the field laboratory took no more than 60 minutes and was performed with the use of a motorbike. Samples from the field laboratory were transported to the Hanoi University of Agriculture (HUA) by car, which took between 6 and 10 hours. In the case of deep-frozen material, the cool chain was usually maintained during the transportation period; the deep-frozen material was tightly packed in an actively cooled box.

At HUA, another laboratory was established. In this laboratory, samples were processed, packed and sent to the University of Hohenheim (UHOH), Germany for further analysis. For example, the analysis of the proximate composition of the feed material was carried out at this location.

Name **FARMERS' NAME** Date: *1.4.2005*
Weather: *cool and cloudy* Rainfall (mm): *no rain*

Fish feed application

Feed	Variety and specification	Weight of feed applied (kg)	Feed parts applied
Banana leaves	"Nguon" ☐ Banana ☒ Others* ☐	*15*	*Leaf with vein*
Cassava leaves	Name of variety______		
Maize leaves	Name of variety ______		
„Long Vuc" grass	Roots ☒ no roots ☐	*3.5*	
Napier grass	Roots ☐ no roots ☐		
Mixed grass from paddy fields	Estimated percentages of important grasses		
Rice bran	Boiled ☐, not boiled ☐, boiled with cassava ☐, Others* ☐		

Manure application

Soure of manure	Application form	Site of collection	Current animal feed	Weight of manure (kg)
Buffalo	Dry ☐ Fresh *X* Processed* ☐	Own animal ☒, collected ☐	*Grass and straw*	5.5
Cattle	Dry ☐ Fresh ☐ Processed* ☐	Own animal ☐, collected ☐		
Pig	Dry ☐ Fresh ☐ Processed* ☐	Own animal ☐, collected ☐		
Green manure	Name? Dry ☐ Fresh ☐ Processed* ☐			

Fish removals

Fish species	Reason for fish removal	Number of fish	Weight of total fish (kg)	In case of selling: price per kg?
Tilapia	Death ☐, Home consumption ☒, Gift ☐, Sale ☐	*12*	*0.8*	
	Death ☐, Home consumption ☐, Gift ☐, Sale ☐			
	Death ☐, Home consumption ☐, Gift ☐, Sale ☐			

Time spent for pond: *60* **minutes**
Main activities of the day: *Weeding of paddy fields*
Products sold that day: ______ **amount:** ______ **kg; price:** ______ **VND**
Today there is water in- and outflow: ☐; no in-and outflow ☒; only inflow ☐; only outflow ☐

Remarks and *
Water level is very low, fish came up to surface (early morning)

Figure 10: An example of a filled-out sheet of a farmer's record book (translated from Vietnamese)

3.3.4 Measurements of dissolved oxygen contents, water temperatures, pH, Secchi disk depths and redox potentials in the ponds

In order to survey the limnological conditions, small bamboo platforms were constructed and placed in the middle of the case study ponds. Every month around the same day, from those platforms, limnological conditions were monitored twice daily, at 8 a.m. and 4 p.m. Dissolved oxygen (DO), temperature and pH were measured at three levels of the water column as well as in the in- and outflowing water. During several days and in different seasons, DO, temperature as well as pH measurements were taken every half-hour or hour over the course of a day. Measurements of the redox potential were carried out in the middle of the water column. An example of the parameter recorded over a sampling day are shown in a filled-out sampling sheet, Figure 11.

DO levels, water temperatures, pH and redox potentials were measured using the multi-parameter instrument pH/Oxi 340i (WTW, Germany) with the following electrodes: DO and temperature: CellOx 325, water pH: SenTix 21 and redox potential: SenTix ORP. The transparency of the ponds was determined using a Secchi disk (diameter: 25 cm), and the colour of pond was evaluated with the naked eye.

3.3.5 Determination of the water flow

The water flow through the ponds was evaluated by measuring the time required for filling a graduated vessel. Water was either measured at the inlet, outlet or both, depending on the pond construction (e.g. use of water-carrying surface pipes versus subsurface water exchange). The mean time required for exchanging the pond water was calculated using the following formula:

Average pond depth (m) x pond size (m^2) x 1000 / Water flow (l min^{-1}) x 60 x 24.

3.3.6 Redox potential and pH of pond mud

The redox potential and pH of pond mud were recorded once in the morning from points around the platform. In order to do this, a tube was constructed and mud was collected by creating a vacuum in the tube. Electrodes (redox: SenTix ORP; pH: SenTix Sp) were then placed directly into the middle of the collected mud. The redox potential values measured in $E_{Ag/AgCl}$ were converted into E_H ($E_H = E_{Ag/AgCl} + E_{Ref}$). The mud depth was determined at the iron pole used for measuring the pond depth (see 3.3.2).

Name of farmer: *FARMERS' NAME* **Date:** *16.05.* **2005**

	Middle of pond (surface)	Middle of pond (middle)	Middle of pond (near bottom)	Pond mud	Water inflow	Water outflow
Morning sampling (time: *7.50* **)**						
DO (mg l^{-1})	*1.42*	*1.24*	*1.21*	x	*2.57*	*0.75*
Temperature (°C)	*28.9*	*28.8*	*28.8*	x	*27.6*	*28.7*
pH	*7.45*	*7.45*	*6.99*	*6.61*	*7.38*	*7.38*
ORB (measured value)	x	*212*	*148*	*-248*	*168*	*182*
Calculation of water amount (e.g. sec/10 l)	x	x	x	x	*s / 10 l*	*n.d.*
Time (for calculating water amount)	x	x	x	x	*133.33*	*n.d.*
Secchi depth (cm)	*33*					
Plankton (litre and remarks)	*50 l*					
Colour of pond	*greenish-milky*					
Weather	*sunny and hot*					
Pond depth	*88 (without pond mud), 101 (with pond mud)*					
Remarks	*no*					
Collection of water samples for photometric analysis (bottle nr.)	x	1	x	x	2	3
Afternoon sampling (time: *4.05* **)**						
DO (mg l^{-1})	*6.84*	*5.76*	*5.75*	x	*5.29*	*4.58*
Temperature (°C)	*32.1*	*32.1*	*32.0*	x	*29.9*	*32.0*
pH	*7.81*	*7.78*	*7.78*	x	*7.62*	*7.81*
ORB (measured value)	x	*187*	x	x	*187*	*210*
Calculation of water amount (e.g. sec/10 l)	x	x	x	x	*n.d.*	*n.d.*
Time (for calculating water amount)	x	x	x	x	*n.d.*	*n.d.*
Secchi depth (cm)	*33*					
Colour of pond	*brownish/reddish, milky*					
Weather	*sunny and hot*					
Remarks	*no*					

Figure 11: A filled-out sheet for the water sampling of a case study pond in a given day

3.3.7 Plankton sampling

Plankton was collected once monthly (between 9 and 10 a.m.) from the mid to upper level of pond with the use of jars; plankton was sieved through a hand net with a mesh size of 20 µm. In the case that there was little visible occurrence of plankton, the amount of water used was usually 50 l, and in the case of higher densities, the water amount was reduced. Plankton was collected in a 100 ml jar and preserved with formalin (4%).

For the measurement of phytoplankton, 1 ml was removed and mixed with distilled water to create a sample of 10 ml. Of this sample, 1 ml was put into a 1 000 cell counting chamber (Sedgewick Rafter), where 100 cells of phytoplankton were counted twice and classified into classes and genera. The allocation of divisions and classes follows the classification provided by Strasburger (1991). The number of phytoplankton counted was then extrapolated to the proximate individuals found in a litre. The formula used for plankton collected from 50 l of water is as follows: X = (Phytoplankton counted x 10 x 10 x 100)/50 = Phytoplankton counted x 200.

For zooplankton analysis, 1 ml of the 100 ml sample was removed and put into a Bogorov counting chamber. All zooplankton individuals were counted and classified into genera. The procedure was repeated. The total number of zooplankton found in 2 ml corresponds (from a 50 l sample) to the number of zooplankton in 1 litre (X = Zooplankton count x 50/50).

The complete plankton (including the samples used for the plankton counts) was filtered on a pre-weight glass microfibre filter (Whatman, 1822-047) and dried in an oven at 65°C to a constant weight. The DM of the plankton (in mg l^{-1} from a 50 l-sample) was determined as follows: Total final weight (sample + paper, mg) – weight of filter paper (mg))/50. The analysis of plankton was carried out with the help of skilled staff of the Research Institute of Aquaculture No. 1 (RIA-1), Hanoi.

3.3.8 Determination of fish stocks and fish transfers and measurements of weights and lengths of individual fish

In order to check fish stocks at the beginning and end of the cooperation period, three-fourths of the pond water was drained and fish were caught with the use of multiple seining. Fish were then collected in a net in the pond and counted and weighed based on species. Around 10% of each fish species in a given sample or harvest day were randomly selected and the weight as well as the standard body length (which excludes the length of the caudal fin) of the individual fish was determined.

All fish were weighed at the beginning and end of the cooperation and, whenever possible, during the major stocking and harvesting procedures. The small fish transfers (e.g. removal of fish for consumption), however, were determined from the farmers' diaries. In addition, fish were regularly caught with lift or cast nets in order to monitor the fish growth.

3.3.9 Collection and analysis of feed and manure

Over 12 months, samples of fresh feed and manure applied to the case study ponds were collected from farmers, immediately weighed and packed into freezing bags directly at the farm site. The samples were brought to the field laboratory and immediately deep-frozen (at -18°C), later transported to HUA and again stored in a deep-freezer. Deep-frozen material was dried using the freeze-dryer Steris GT2 and was reweighed afterwards in order to calculate the amount of dry matter. The dried material was stored, packed and sent to UHOH for further analysis.

Representative samples (n≥2) of the applied items were used for the determination of the gross chemical composition. Leaf veins of banana and petioles of cassava (both usually not eaten by fish) were separated from the leaves and softer parts; both fractions were dried and analysed separately.

For the chemical composition of fish feed and manure, the dry matter (DM) was measured by drying the material to a constant weight at 105°C and the crude ash (CA) by burning it in an oven at 500°C. Crude protein (CP) was analysed with the utilization of the macro-Kjeldahl method (N x 6.25), lipid by extraction with petroleum ether (ether extract, EE) based on the standard methods of the Association of Official Analytical Chemists (AOAC, 1990). Neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin (L) were determined according to Van Soest et al. (1991). The gross energy (GE) was determined with a bomb calorimeter (IKA C 7000, Janke & Kunkel IKA Analysentechnik, Germany).

The amounts of feed and manure that were applied to the ponds were taken from the diaries maintained by the farmers. In order to determine the proportions of edible to non-edible parts in the case of banana and cassava leaves, both parts (as applied to the ponds) were weighed together, separated and weighed again individually.

3.3.10 Determination of fish intestine lengths and contents as well as liver weights

Fish of different species were randomly caught from the case study ponds with dip or cast nets and transported in a plastic box on a motorbike to the field laboratory. Here, fish were slaughtered and dissected. Besides fish body weights and lengths, the lengths of the intestines as well as the weight of the livers were determined. Afterwards, the intestines were inserted into a formalin solution (10%). At HUA, the intestine contents were examined under a microscope and the contents determined.

3.3.11 Formulas

Additional formulas of different parameters used in the present study are shown in Table 6.

Table 6: Formulas of different parameters

Parameter	Calculation
Weight gain (g)	Final body weight (g) – initial body weight (g)
Specific growth rate, SGR (%)	(ln final body weight (g) – ln initial body weight (g)) / time (days) x 100
Food conversion ratio, FCR	Feed applied (g, DM) / live weight gain (g)
Protein efficiency ratio, PER	Body weight gain (g, FM) / crude protein fed (g)
Condition factor, CF	Body weight (g, FM)/ standard body length $(cm)^3$ x 100
Relative intestine length, RIL	Length of intestine (cm) / standard body length (cm)
Hepato-somatic index, HSI	Weight of liver (g, FM) / body weight (g, FM) x 100

DM = Dry matter; FM = Fresh matter

3.3.12 Presentation of data

The values reported are means of the six case study farms along with standard deviation. Since the size of the ponds as well as the periods of observation differed among the case study ponds, the data is usually converted in order to correspond to a hectare and year for better comparability. The reference period is usually addressed as the "cooperation period" (see Table 5). However, there are certain calculations based on other time frames, e.g. the "major rearing period" (defined as the period from the major stocking to the major harvesting procedures).

4 Results: Short description of the study area (macro level)

4.1 Crop, livestock and fish production in the study area

The Chieng Khoi, Sap Vat and Vieng Lan communes are primarily dominated by Black Thai settlements, usually located in the valleys in paddy field areas. Paddy rice is the major food crop in this region and is usually used for subsistence. Maize and cassava are the main rain-fed crops, planted on the hillsides as cash crops. Also, banana and occasionally cotton are planted in upland fields, whereas other fruits and vegetables are primarily produced in home gardens. Common livestock raised here consist of buffalos, cattle, goats, pigs and poultry. Table 7 shows the number of households, number of people living in the studied communes as well as the major land uses in this area. According to the village headmen, over 63% of households in the study area own at least one fishpond, and the average pond area is 970 m^2 per fish-producing household. The total pond area comprises approximately 115.2 ha, making up almost half of the total paddy rice area. Fishponds are integrated into the overall farming as well as the irrigation systems.

The typical pond systems in these communes can be characterized as polyculture with grass carp as the main species. Ponds are supplied with crop residues, including crop leaves, weeds as well as manure from ruminants and pigs. In most cases, ponds have a continuous water-flow throughout the year. Water is usually provided by a shared irrigation system or spring water. Typically, ponds are managed at the household level, but in some exceptional cases, ponds belong to the commune. These ponds can be leased by individuals for a certain period of time.

4.2 Location of the case study ponds within the surrounding irrigation systems

The case study ponds CK1, CK2 and CK3 belong to the villages Me and Tum (Chieng Khoi commune), located on a mid-level plateau between a mountain ridge and the Yen Chau valley, approximately 2-3 km from the Yen Chau centre. The investigated ponds are all located in an area that is mainly used for paddy production as well as for residential use. The average altitude of the ponds is 450 m above sea level, and their positions in correlation to the surrounding watershed are shown in Figure 12. The irrigation system in Chieng Khoi mainly obtains its water from a storage lake, several hectares in size. This lake accumulates water from the surrounding mountains and underground springs. The Chieng Khoi dam is managed by a water management company under the Department of Agriculture and Rural

Development in Son La. This company regulates the water flow in the main concrete water canal; however, the distribution of water within small canals, fields and ponds is mainly regulated on the communal and village levels. Among the different villages, water is distributed through a network of irrigation canals and often flows from the canals into paddy fields and then into ponds and vice versa. Canals are either dug out or reinforced with concrete; the positions of the small earthen canals are frequently changed.

The dam provides water for all six villages in Chieng Khoi commune as well as to the villages Bat and Dong in Sap Vat commune. The water management company considers the water holding capacity in the Chieng Khoi dam to be relatively low, frequently leading to water shortages in the dry season. However, other important water sources include springs and precipitation.

The case study ponds SV1, SV2 and SV3 are all situated in the village Bat (Sap Vat commune), each located a maximum of 200 m from the farmers' houses and approximately 1-2 km from Yen Chau town. Their locations within the surrounding watershed are shown in Figure 13. Bat is located downstream of the Chieng Khoi commune, whose irrigation system ends in this village and the neighbouring village Dong. The altitudes of the case study ponds are approximately 275 m above sea level, and besides the irrigation water from Chieng Khoi, these case study ponds are also supplied with water from the Vat stream, springs and precipitation. Over the course of several months in 2005, water was very limited in the village, partly due to flood damage to a dam in 2004.

Figure14 shows the location of the case study ponds VL1, VL2 and VL3 in the village Huai Qua (Vieng Lan commune), which are all situated in upland field areas at walking distances of about 1-2 km from farmers' houses and approximately 3-4 km from Yen Chau town. Paths to the ponds are very steep in some parts and impassable on motorbikes in the rainy season. These ponds are found at an altitude of approximately 300 m above sea level and are surrounded by rain-fed maize, cassava and banana fields. Water in all these case study ponds is supplied by spring water that enters the pond through small streams and canals as well as precipitation.

Table 7: Villages, population and land use area of Chieng Khoi, Sap Vat and Vieng Lan communes

Name of village	Number of HHs[1]	Number of inhabitants[1]	Main ethnic group[1]	Paddy area (ha)[1]	Upland area (ha)[1]	Pond area (ha)[1]	Fish producing HHs[2]	Major crops produced in the village[2]
Chieng Khoi (CK) commune								
Hiem	116	593	Black Thai	12.6	113.0	15.0	~ 116	Rice, maize, cassava
Me	110	514	Black Thai	14.9	38.4	13.1	~ 110	Rice, maize, cassava
Na Dong	66	309	Black Thai	12.2	32.8	6.5	~ 60	Rice, maize, cassava
Ngoang	64	307	Black Thai	10.7	29.7	4.0	~ 64	Rice, maize, cassava
Put	97	448	Black Thai	10.8	46.7	10.1	~ 90	Rice, maize, cassava
Tum	119	586	Black Thai	17.7	47.4	14.2	~ 119	Rice, maize, cassava
Total Chieng Khoi	572	2 757		79.2	308.0	62.9	~ 559	
Sap Vat (SV) commune								
Dong	54	233	Black Thai	9.3	40.0	2.7	> 40	Rice, maize, cassava, forest
Bat	72	327	Black Thai	16.6	58.0	7.0	~ 50	Rice, maize, cassava
Khoong	54	228	Black Thai	7.8	37.0	1.6	~ 18	Rice, maize
Na Khai	91	367	Black Thai	12.8	70.4	7.9	> 10	Maize, cassava
Nghe	87	378	Black Thai	10.0	40.0	1.0	~ 5	Rice, maize
Sai	87	387	Black Thai	13.0	60.0	5.0	~ 50	Rice, maize
Met	58	246	Black Thai	9.1	72.5	1.4	~ 15	Rice, maize, cassava, cotton
Khin	78	335	Black Thai	7.2	88.9	4.8	~ 60	Rice, maize, cassava
Kha	77	340	Black Thai	6.2	88.0	3.4	~ 55	Rice, maize
Na Pa	75	336	Black Thai	3.7	96.3	1.4	~ 60	Rice, maize
Pa Sang	51	286	H'Mong	0.0	54.0	0.0	n.d.	n.d.
Hin Nam	41	126	Kinh	0.0	0.0	0.1	n.d.	n.d.
Total Sap Vat	825	3 589		95.7	705.1	36.3	≥ 363	
Vieng Lan (VL) commune								
Na Va	123	559	Black Thai	23.2	201.2	2.0	~ 50	Rice, maize, cassava, cotton
Muong Vat	53	234	Black Thai	5.7	54.8	1.0	n.d.	n.d.
Kho Vang	112	498	Black Thai	13.6	124.6	7.0	~ 80	Rice, maize, cassava
Huai Qua	90	426	Black Thai	10.4	229.4	2.0	~ 86	Rice, maize, cassava
Huoi He	54	258	Black Thai	7.3	34.9	1.4	~ 50	Rice, maize, cassava
Sop He	40	167	Black Thai	3.4	n.d.	2.6	n.d.	n.d.
Total Vieng Lan	472	2 142		63.6	≥ 644.9	16.0	≥ 266	
Total CK, SV, VL	1 869	8 488		238.5	≥ 1 658.0	115.2	≥ 1 188	

HH = Household; n.d. = not determined

[1]Data collected from communal People's Committees; [2]Data collected from village headmen in 2005; "fish producing households" bases on estimations of village headmen

4.3 Fishing and aquaculture activities in the irrigation system

Several sub-systems of the overall irrigation system are sites where fishing activity takes place (see Table 8). Besides fish production in the earthen ponds, farmers catch self-recruiting species, such as fish, crabs, shrimp, frogs and snails, in communal water bodies, e.g. streams and canals as well as in the paddy fields. However, farmers report a decline in catches of these self-recruiting species over time. Paddy fields are closely linked to fishponds regarding water and other resources, but the culturing of fish in paddy fields is not practiced in the study area.

Three farmers jointly leased the Chieng Khoi storage lake for fish farming over a period of 5 years. These farmers stocked different carp species and tilapia, harvested fish using seine nets and marketed them locally. The fish farmers applied certain amounts of feed, including leaves and grasses; however, they were not allowed to fertilize the lake with manure, since water from the lake is also used for other purposes such as for bathing in the adjacent communes. According to a lessee of the lake, farmers catch around 4-5 tons per year from the total area of 24 hectares. However, the lake has not been measured and the yields were not monitored during the study period.

Table 8: Fishery and aquaculture activities in different sub-systems of the irrigation system in Chieng Khoi

	Water reservoir	Water canals	Ponds	Streams
Use in irrigation system	Water collection and storage	Water distribution	On-farm water use	Partly waste-water removal
Fisheries activities	Fish production	Harvest of SRS's, no fish production in net cages	Fish production and harvest of SRS's	Harvest of SRS's, no fish production in net cages
Users of aquatic products	Individual households (by leasing)	All	Individual households or commune	All

SRS = Self-recruiting species

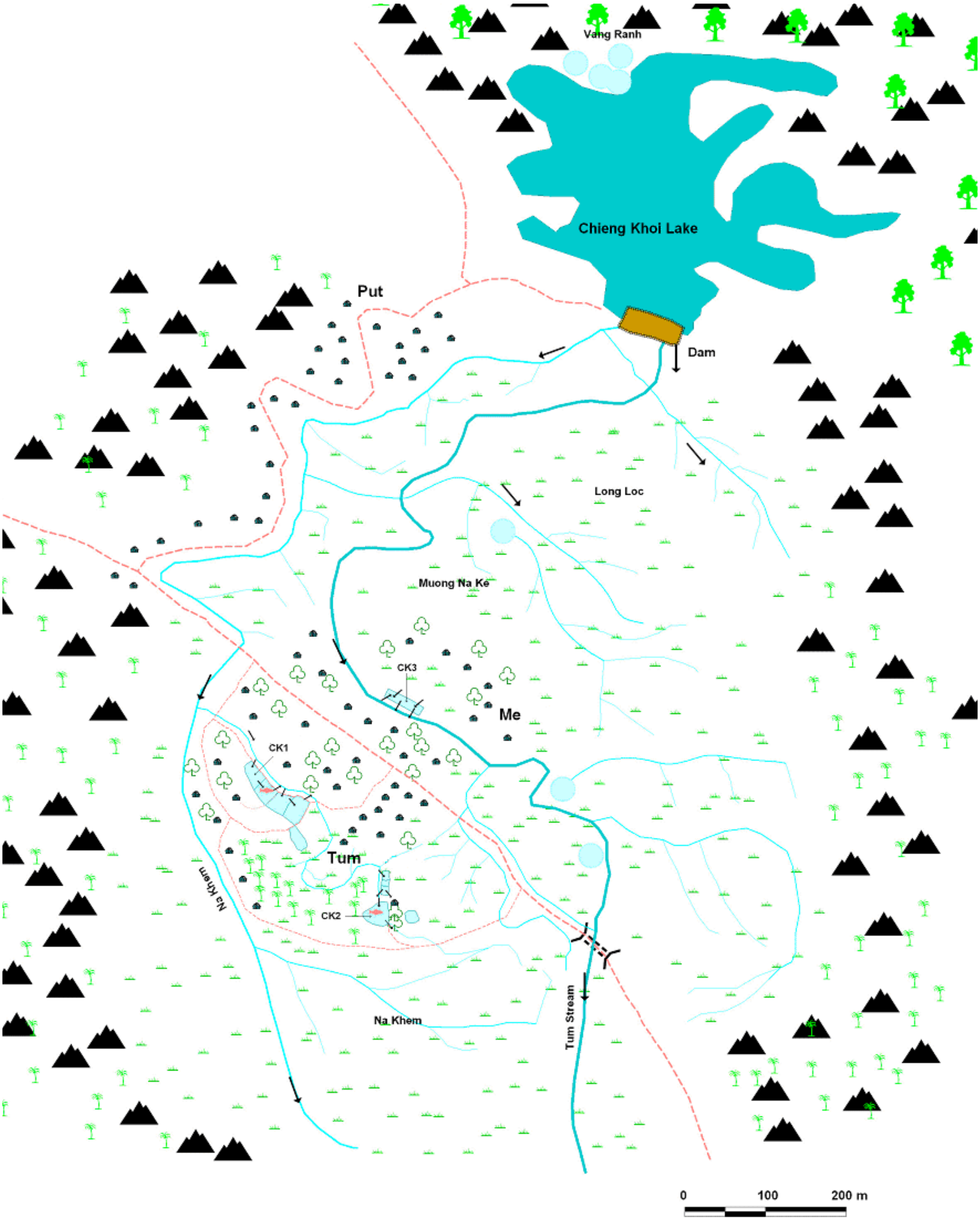


Figure 12: Sketch of case study ponds (CSP) of Chieng Khoi commune showing the land use pattern and water supply system in surrounding areas

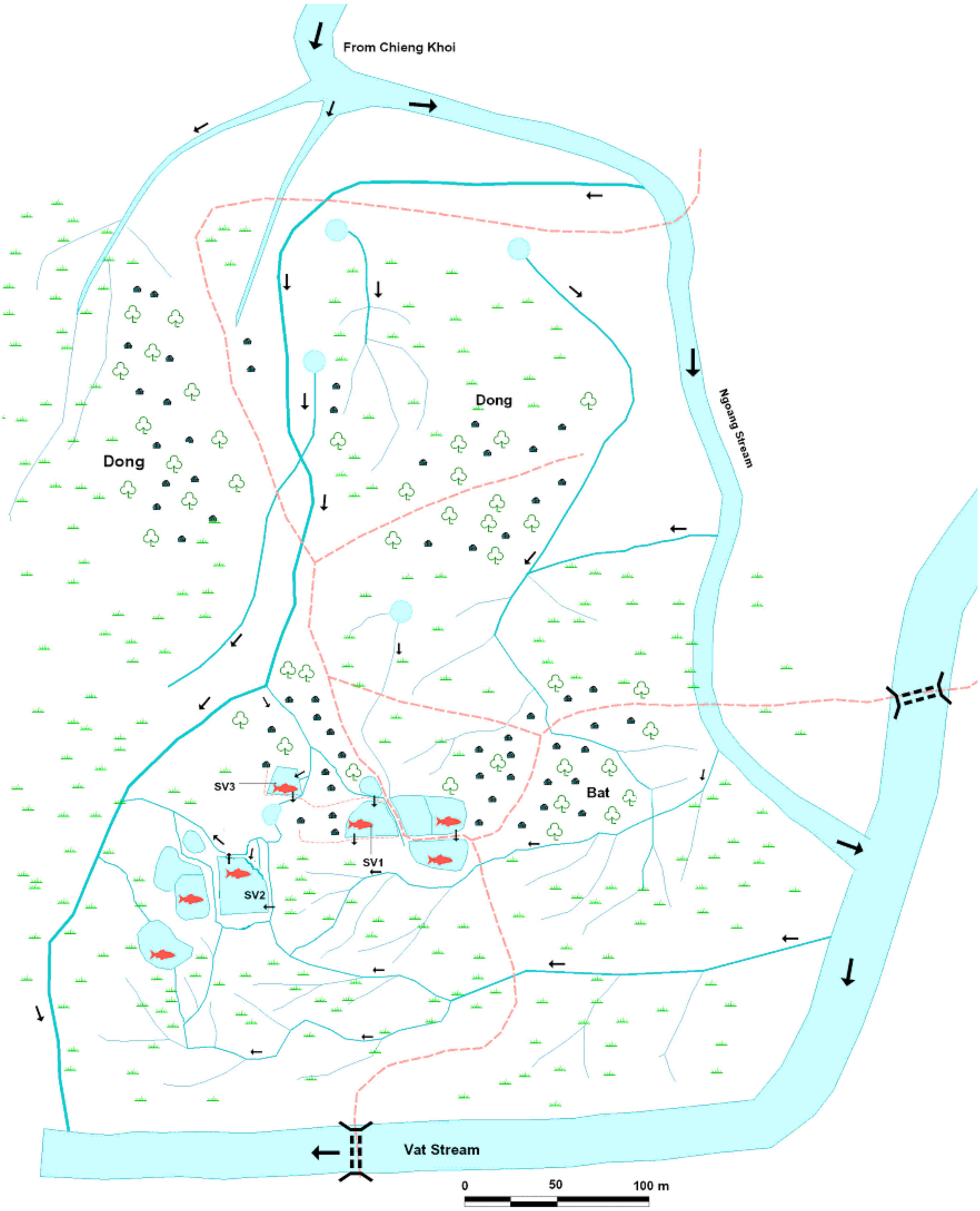


Figure 13: Sketch of case study ponds (CSP) of Sap Vat commune showing the land use pattern and water supply system in surrounding areas

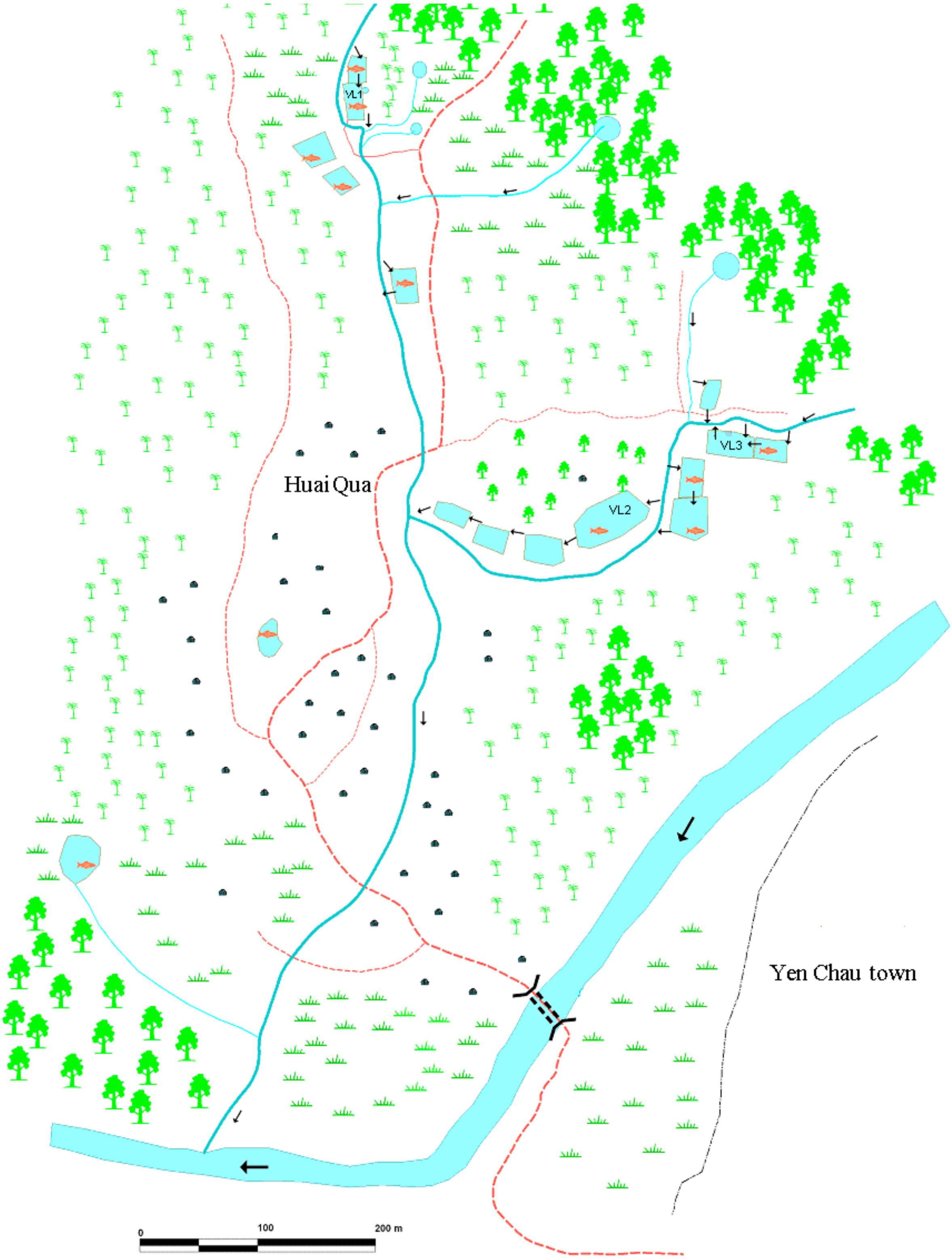


Figure 14: Sketch of case study ponds (CSP) of Vieng Lan commune showing the land use pattern and water supply system in surrounding areas

5 Results: The local aquaculture and agriculture system (meso level)

5.1 Description of the local aquaculture system

5.1.1 Pond system

According to interviewed farmers, fish farming in the region began over 50 years ago. Since that time, the number of farmers who adopted aquaculture has steadily increased. About half of all ponds belonging to 155 farmers were created within the past 20 years. In all cases, the motivation for digging a body of water was fish production. The majority of ponds (87.8%; survey 2) have so-called "Red Book certificates", which regulate land use rights; most of them have been in effect from 1999 onwards. However, there are also cases where farmers unofficially transferred use rights of ponds to relatives.

Farmers distinguish between two types of ponds: nursery and grow-out ponds. In nursery ponds, fish are raised until they reach a certain size and are then either sold to other farmers or transferred to bigger ponds for further grow-out until they reach marketable sizes. The use of a pond for either nursing or growing out fish often changes; thus, there are usually no ponds exclusively used for one purpose only. On average, fish farmer households (5 individuals) own 1.6 ponds, each with a mean size of 792 m^2 (130 - 3 500 m^2). In comparison, the average size of nursery ponds was 413 m^2 during the time of the interviews. Ponds are often situated in the valleys between paddy plots or in residential areas, but the majority are found between rainfed upland fields (62%; survey 2). Ponds are earthen, there are rarely dykes made from concrete or bricks, they are often surrounded by trees such as bamboo or fruit trees and some pond embankments are used for vegetable production. Almost all farmers have tree branches in their ponds to prevent thieves from angling or netting.

Water is primarily supplied by the general irrigation system, streams, springs or precipitation. Around 76% of the ponds are used during the whole year, while the remaining ones are used only seasonally, since they rely on precipitation as their major water source. When farmers were asked how they assess the quality of different water sources, they usually preferred spring water since it is considered as being clean.

Typically, water flows through ponds, and in 32% of the cases, there is a constant flow throughout the year. In 52% of the ponds, water flow occurs only over certain periods, while the remaining ponds have no water flow at all (survey 2). Led to the ponds by means of gravity, the water is let into and out of the ponds either through small trenches or bamboo pipes. Bamboo sticks, mats or mesh sheets are placed at the inlets and outlets to protect against the entry of unwanted fish species and bigger dirt particles as well as to prevent the escape of cultured fish. Sometimes, bamboo sticks surround the outlet in order to prevent floating feed material from clogging up the sheet covering the outlet. The water in those ponds that are located in the valleys is usually supplied by the shared irrigation system. In some cases, water from paddy plots flows directly into the ponds or water is supplied by irrigation canals that formerly passed through rice fields. Activities carried out by individual farmers, such as the application of pesticide or even the practice of washing clothes in the canals, may influence connected ponds. Springs and precipitation make up the major water sources of ponds situated in the upland areas. In some cases, ponds are located next to each other, allowing water from the upper level to flow by gravity from pond to pond.

In general, farmers consider a continuous water-flow to be better for fish production than stagnant water because of the frequent exchange of pond water. Some farmers stated that the water-flow can also be harmful in the case of pesticides entering the ponds from paddy fields. It is seen as a critical issue when ponds are located next to each other and water flows from the upper to the lower pond, since diseases can be transmitted in this way and the water quality in the lower ponds can be affected. It is considered as good when pond water flows out into the paddy fields since the water can deliver nutrients to the crops. Water flow is sometimes stopped in the case of high turbidity in inflowing water, e.g. after heavy rainfall.

With the use of inlets and outlets, the water flow in a pond can be partly controlled. However, the ability to do this is dependent on the pond’s location and the nature of the water source. Furthermore, farmers are often unable to act independently from other farming activities. For example, the water flow cannot be stopped when the outflowing water is required for irrigation of the adjacent paddy fields. This is also the case with ponds located next to each other, where water is supplied to the lower pond from the upper pond. Furthermore, it is often not possible to by-pass water from the ponds or fields. Additionally, inlets and outlets are sometimes located below the water surface, rendering the regulation of the water flow more difficult.

Even though most of the ponds can be drained, it is often not possible to completely remove the water for the purpose of drying out the pond mud. Many ponds have small water sources on the pond floor, from which water ascends continuously. Also, pond drainage depends on other farming activities. For instance, a pond with an adjacent paddy field located lower in relation to the pond cannot be drained shortly before rice harvest because the field must remain dry.

40% of ponds are never dried out and 26% are not regularly dried out before fish stocking. Also, the removal of pond mud is considered rather atypical. In 65% of ponds, farmers never remove pond mud, and those who do so, use it mainly for repairing pond dykes and in a few cases for fertilizing gardens or rice seedbeds (survey 2).

5.1.2 Cultured species and source of fish

The main source for juvenile fish in the study area is a hatchery in Son La town, which was established by the government in the 1960s and became privatized in 2004. A total of ten hatcheries exist in this province, but only four hatcheries (Son La, Song Ma, Thuan Chau and Phu Yen) are able to conduct artificial reproduction. The remaining hatcheries (or nurseries, respectively), such as the hatchery/nursery of Yen Chau, Mai Son and Moc Chau, partly purchase fry from bigger hatcheries and raise them up to a certain size before selling them to farmers. According to the operators of the Son La hatchery, they produced 15 million fish in 2005, 2-3 million of which were sold to Yen Chau.

In the Yen Chau hatchery/nursery, which was privatized in 1993, only common carp are produced, while all other fish are purchased as fry from the hatchery in Son La. The manager of the Yen Chau hatchery reported a fry survival rate of 30-40% and a total sold volume of 1.5 million fry in 2005. Both Son La and Yen Chau hatcheries grow some fish up to marketable size in order to gain additional income by selling the fish directly to consumers.

The most important fish species produced by local hatcheries include grass carp, mud carp, Indian carp such as mrigal and rohu, common carp, silver carp, bighead carp, silver barb and (monosex) tilapia. Most of the fish produced in these hatcheries are grass carp (≥ 50%) followed by mud carp and mrigal. Table 9 shows the names of the fish in Latin and Vietnamese. The Vietnamese word "*Cá Mè*" stands for both silver carp and bighead carp, and the word "*Cá Trôi*" refers to mud carp, mrigal and rohu. This can regularly lead to confusion, since farmers as well as consumers often consider the different fish species to be the same, in both terminology and species. During the interviews, it was often the case that the exact fish species could not be clarified. Therefore, the following text frequently refers to the fish groups (mud carp/mrigal/rohu and bighead/silver carp) instead of the individual species.

In 1967, the Son La hatchery started collecting broodstock fish (except tilapia) originating from the province Son La. The broodstock is kept year round in net cages in ponds. However, over the years, larger fish were collected from farmers and added to the stock. In the hatchery, fish reproduction usually takes place in the first half of the year. It is typically the case that broodstock males and females are randomly collected and crossed through the application of hormonal injections.

The typical feeds applied to small grass carp in the hatchery are shown in Figure 15. Once grass carp are hatched and start feeding on exogenous food, they are supplied the ground yolk from duck eggs. After two days of feeding, fry are transferred to a fishpond and supplemented with grass and leaves, germinated rice and soybean meal.

Table 9: Typical fish species produced in the hatcheries in Son La and Yen Chau in English, Latin and Vietnamese languages

Common name in English	Latin name	Vietnamese name
Grass carp	*Ctenopharyngodon idella*	Cá Trắm cỏ
Mud carp	*Cirrhinus molitorella*	Cá Trôi Việt Nam
Mrigal	*Cirrhinus cirrhosus*	Cá Trôi Mrigal
Rohu	*Labeo rohita*	Cá Trôi Rôhu
Common carp	*Cyprinus carpio*	Cá Chép
Silver carp	*Hypophthalmichthys molitrix*	Cá Mè trắng
Bighead carp	*Artistichthys nobilis*	Cá Mè hoa
Nile tilapia	*Oreochromis niloticus*	Cá Rô phi
Common silver barb	*Barbodes gonionotus*	Cá Mè vinh

Individual farmers seeking new fish for stocking either contact a farmers' union or buy them directly. They purchase the fish either from hatcheries in Son La or Yen Chau town, from fish traders of other provinces or from other farmers who grow fish to a certain size. Farmers' unions (e.g. of a village or commune), on the other hand, organize fish purchases from distant locations or make appointments with the fish traders. Often, farmers buy fish from different sources and practice multiple stocking.

Figure 15 shows the route of grass carp from siring to the farmer's grow-out pond as well as the stage when they are purchased by farmers. When farmers were asked about the stocking size of fish, they regularly talked about "chopstick" or "toothpick" size; therefore, the "farmers' language" had to be "translated" into the "language of the interviewer", which regularly required some time for clarification.

Very seldom do farmers purchase fish as fingerlings, since they usually prefer advanced fry with a body length of 2-3 cm. This is because the transport of these fish requires less effort and the price of small fish is lower. According to the Son La and Yen Chau hatcheries, 50-70% of fish are sold when they are at this size. However, in 32% of the ponds belonging to those farmers who were interviewed with the questionnaire, grass carp were purchased from local nursery ponds and then stocked with bigger sizes (≥ 300 g $fish^{-1}$) for further grow-out. An argument for this technique is that there is a quicker growth potential for larger fish compared to small fish. Additionally, there is a lower risk for the presence of fish seed, which is infected with disease from the hatcheries.

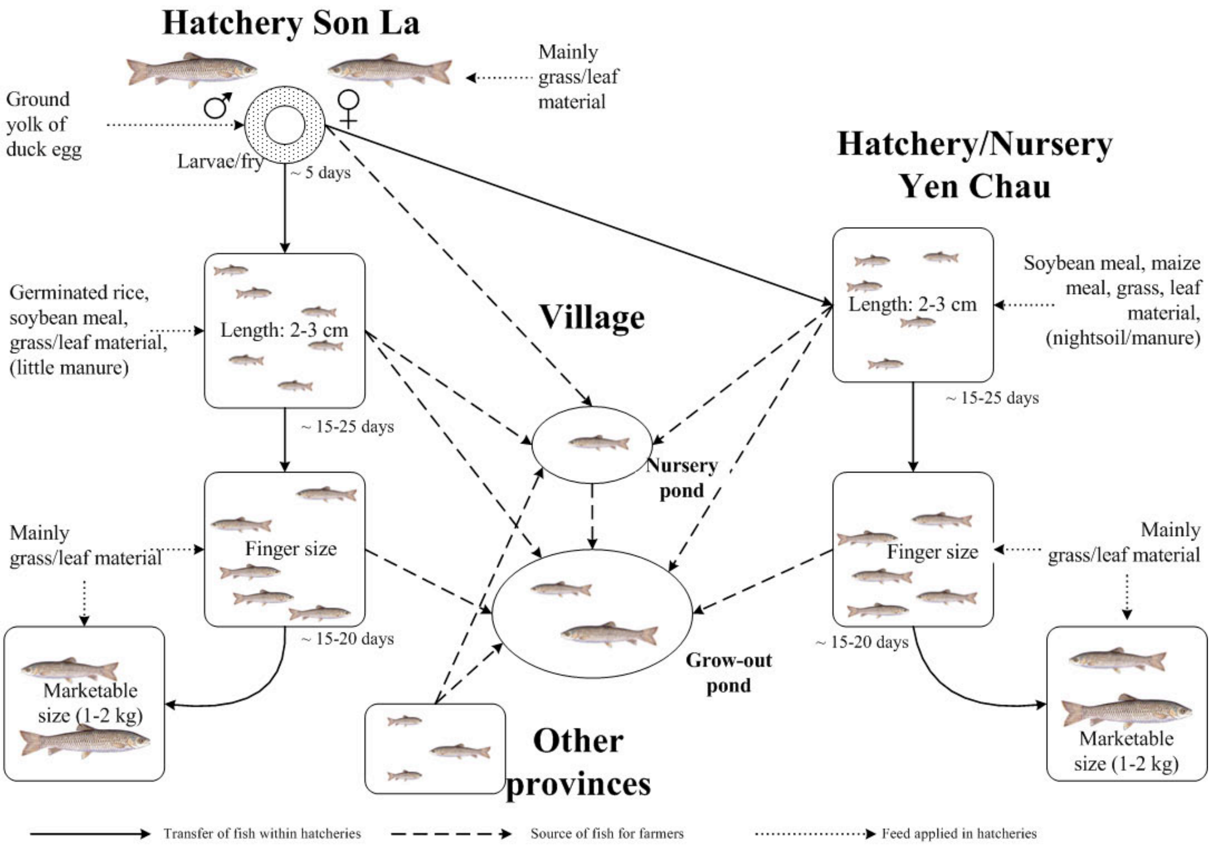


Figure 15: The route of grass carp movement from siring to the grow-out pond, the stage when they are sold to farmers and the feed they receive in hatcheries

Typical prices for juvenile grass carp in the region are shown in Table 10. Prices usually depend on fish size and are the same for most of the produced fish species. However, several species are more expensive including common carp and monosex tilapia, which are sex-reversed by means of synthetic testosterone. Only rarely do farmers buy common carp and tilapia from local hatcheries, which can be explained by the fact that these fish species reproduce naturally in farmers' ponds. However, a continuous supply of fish is often not guaranteed, thus farmers' stocking often depends on fish availability rather than on long-term planning.

The hatchery staff members usually transport fish by jeep or motorbike with an oxygen supply. They report that fish quality decreases during long transports to remote areas.

If the purchased quantity of fish is large, they are often delivered by the hatchery; otherwise, farmers purchase fish directly and transport them in plastic bags placed in a basket on a motorbike or carried while walking. Also in these cases, fish can be negatively affected during the course of long transports. It was also observed that farmers frequently release fish into their ponds without preconditioning them to the new environment, which often leads to high fish mortality in the following days.

Table 10: Typical prices for juvenile grass carp in Son La province (state: April 2005)

Size of grass carp	Local prices
Fry	2-4 VND fry^{-1}
Advanced fry (length 2-3 cm)	40 – 100 VND fry^{-1}
Fingerlings	~ 1 000 VND $fingerling^{-1}$
Young fish (e.g. ~ 500 g)	20 000 - 25 000 VND kg^{-1}

VND = Vietnamese Dong

The typical stocking period takes place from March to June for fish purchased from the hatcheries. During their last major stocking procedure, farmers stocked an average of 1.6 fish m^{-2} in grow-out ponds and 7.1 fish m^{-2} in nursery ponds, where grass carp were usually the most prevalent fish species in terms of numbers as well as biomass (survey 2). The number of fish stocked as well as the combination of species generally depends on both fish availability and farmers' liquidity. Also, personal preferences and experiences ("silver carp do never grow in my pond…") influenced farmers' decisions regarding the species combination in the ponds. The farmers interviewed often experienced difficulties remembering the exact amounts of stocked fish, especially when the stocking activity had taken place a long time ago. Additionally, multiple stocking and frequent removal and transfer of fish makes it difficult to estimate the real numbers of fish stocked. Since common carp and tilapia reproduce in farmers' ponds, farmers usually have no indication of the present amount of those species.

During their last production period, several of the interviewed farmers (4%, survey 2) also reported culturing less typical fish species such as pirapitinga (*Colossoma/Piaractus brachypomus*) and catfish (*Clarias* sp.). The farmers apparently did so based on the advice of local radio and television broadcasts or fish traders. Additionally, 7 out of 85 farmers (survey 2) reported that they stocked snails in their pond.

5.1.3 Feed and manure regime

Typical feeds that are derived from cultivated crops and native plants are shown in Table 11 and 12. Important plant-derived inputs to grow-out ponds include cassava leaves, chopped cassava tubers, peels and fermentation residues. From banana plants, the leaves and hashed young or the soft part of elder (pseudo-) stems are also used as feed. Moreover, the leaves from maize and bamboo and occasionally from mulberry and vegetables serve as fish feed. Additional inputs include the by-products from rice such as rice bran and broken rice. Weeds and other plants are also used as fish feed. Farmers usually collect weeds from paddy fields, dykes or along the road, while aquatic plants are harvested from paddy fields and water bodies (e.g. canals). The most important weed from the paddy fields is barnyard grass (*Echinochloa crusgalli*), which is the grass that is mostly utilized as fish feed. Additionally, all kinds of kitchen leftovers are usually applied to fishponds, which are located near the farmers' houses.

The production as well as the purchase of fish feed is rather unusual. Only 2 farmers reported growing Napier grass (*Pennisetum purpureum*) on pond dykes and only 4 farmers claimed buying rice bran as supplementary feed. However, 3 farmers reported, planting some banana shrubs for the exclusive purpose of harvesting the leaves for fish and livestock (survey 2). Feed is typically not processed prior to its application to the ponds and feeding occurs twice daily, in the morning and afternoon. Many farmers in the region use feeding rings made of bamboo sticks and remove any leftover feed (i.e. stems and petioles from cassava, leaf veins from banana) one to two days after feed application. Commonly, juvenile fish receive rice bran, chopped soft leaves and grass, as well as maize and cassava meal. Also, manure is a typical pond input in nursery as well as grow-out ponds.

Animal-derived pond inputs comprise manure from large ruminants or pigs. Sources of manure are either one's own or neighbouring animals or can also consist of droppings collected from roads. Buffalo dung is by far the most important manure input, frequently applied to 68% of the ponds, followed by cattle (39%) and pig manure (16%). In about 15% of ponds, no manure is applied, since these ponds are located far away from roads or livestock stables, rendering the transport of manure more labour intensive. Manure is typically applied in a fresh but occasionally also in a dried or composted form. The placement of animal pens above ponds is not common in this region. According to the interviewed farmers, this practice exhibits "no tradition" here, and farmers generally prefer to keep their animals (e.g. poultry) directly next to or under their houses in order to avoid theft.

Farmers perceive Siam weed (*Chromolaena odorata*) as green manure. This kind of weed is applied to a third of all ponds, where it degrades slowly and is eaten by fish after a couple of days. Nightsoil (excrements of humans) is very rarely applied to ponds, and only two out of 155 farmers reported using it as an input.

Farmers' decisions regarding the use of a certain feed at a certain time of the year are often based on the availability of feeds (e.g. use of maize leaves during its growing period), the availability of excess time (e.g. use of rice bran during times of higher workloads) and current farming activities (e.g. use of weeds after hand-weeding crop fields). Often in the case of very high workloads, no feed or manure are applied (e.g. during the construction of a house, harvest season etc.) as well as during times that farmers celebrate festivals (e.g. during the occasion "*Tết*", the Vietnamese New Year).

Fish diets vary between ponds, which usually depends on the location of the pond. Ponds located next to the farmer's house often receive more diverse feed inputs (e.g. kitchen wastes or manure from nearby stables) as compared to those situated farther away. Ponds located between upland fields are supplied almost exclusively with leaves from the surrounding fields.

Table 11: Fish feeds derived from cultivated crops

Crop	Varieties/Species	Crop products used as fish feed
Cassava (*Manihot* sp.)	Local long-term variety ("*Sắn đỏ*"), introduced short-term varieties (locally called "3-month" or "6-month" varieties)	Leaves, meal (in nursery ponds), tubers, peel, residue from cassava fermentation
Banana (*Musa* sp.)	Local variety ("*Chuối tây*"/"*Chuối lá*") with small fruits	Leaves, chopped stems, peels (seldom)
Maize (*Zea* sp.)	Mainly introduced hybrids (e.g. "*Lai 10*")	Leaves, meal (in nursery ponds)
Rice (*Oryza* sp.)	Local sticky rice varieties (e.g. "*Nếp bắc đuôi*") or introduced high yielding varieties (e.g. "*Bắc ưu*"/"*Sán ưu*")	Bran, blades/straw, broken (sorted out) grains, hulls (seldom), residues from rice fermentation
Bamboo (*Bambusa* sp.)		Leaves
Mulberry (*Morus* sp.)	Diverse varieties available (e.g. for fruit or silkworm production)	Leaves
Fodder grass	Napier/Elephant grass (*Pennisetum purpureum*)	Blades of grass
Vegetables	e.g. water dropwort (*Oenanthe javanica*), sweet potato (*Ipomea batatas*), water morning glory (*Ipomea reptans*), cabbage (*Brassica oleracea*)	Leaves and stems
Fruits	e.g. figs (*Ficus glomerata*), tamarind (*Tamarindus indica*)	Fruits and leaves

Table 12: Fish feeds derived from native plants

Type of feed	Source of feed	Species
Grasses and weeds	Paddy fields or dykes, along the road, occasionally from upland fields	Typical weeds from paddy fields or dykes: e.g. *Alternathera sessili; Commelina nudiflora*; *Cyperus imbricatus*; *Cyperus rotundus*; *Digitaria timorensis*; *Echinochloa crusgalli; Eclipta prostrata*; *Kyllinga monocephala*; *Sagitaria sagitifolia*; *Sporobolus indicus*; *Urochloa reptans*; *Wedelia calendulacea*. Typical weeds found along roads and in upland field areas: *Chromolaena odorata,* formerly *Euporarium odoratum* (Siam weed, Christmas bush)
Aquatic plants	Paddy fields or water bodies (e.g. canals)	e.g. Floating watermoss (*Salvinia natans*); Azolla (*Azolla imbricata*); Water lettuce (*Pistia stratiotes*); Duckweed (*Lemna paucicostata*)
Leaves of native trees	Forests and non-cultivated areas	e.g. "*Chuối rừng*" ("Forest banana")

Feed is often limited in the cold and dry season, which can be attributed to various factors; for example, cassava plants frequently lose their leaves in the wintertime and banana leaves rot in the foggy weather. The availability of grass and weeds is also limited, for instance when ruminants graze on fallows.

5.1.4 Pond inputs, investments and labour requirements

In general, no further off-farm inputs are purchased for aquaculture production with the exception of fish seed. Typical commercial aquaculture supplies such as fish medicine, pellet fish feed and lime are currently not available on the district markets. However, some of these products could theoretically be obtained from the provincial capital of Son La.

Only 10% of the farmers invested money for the construction or restoration of ponds, and only two from 85 farmers hired an excavator with a driver for digging a pond (survey 2). However, the digging of ponds with machines can occur given that the pond is accessible and that the farmer is able to finance this capital-intensive technique. Usually, farmers invest in fishing gear, which is frequently repaired and used over several decades. Yet, some farmers choose to construct nets themselves. Farmers typically own lift and cast nets, only a few farmers possess seine nets in addition; nets are frequently shared among neighbours or relatives. Typical local prices for the above-mentioned products and services are shown in Table 13. Currently, farmers do not have to pay fees and taxes for irrigation water and land used for pond purposes.

Table 13: Expenditures for aquaculture-associated devices

	Prices (VND)
Casting net	150 000 - 350 000
Dip net	25 000 - 50 000
Seine net	> 1 000 000
Lime (25 kg)*	~ 50 000
Excavator with driver (per hour)	~ 300 000

*Price in Son La town, not available in Yen Chau

Table 14: Typical time requirements for aquaculture activities

Activity	Typical time requirements
Pond preparation	≤ 1 month
Pond restoration (e.g. dykes)	2-3 days
Collection of feed (rainy season)	120 min daily*
Collection of feed (dry season)	90 min daily*
Final harvest	~ 4-6 hours

*Time spent per total pond area of a household

Typical time requirements for pond construction, pond restoration, daily feed collection and the final harvest are shown in Table 14. In general, fish production in ponds is considered to be labour intensive, particularly the collection and transport of feed. The time spent for feeding depends on various factors, e.g. on the type of feed applied (e.g. cutting grass versus feeding rice bran), transport distances, volumes and weights of feed, size of pond, stocking density and size of fish, season and the age and physical status of the respective farmer. Table 15 demonstrates the typical work distribution in Black Thai fish farmer households. While men are usually in charge of stocking and catching fish for household consumption, women often collect small aquatic products (e.g. snails, shrimps) from the mud and are in charge of selling the products on the markets. In the case of bigger harvests, all household members usually participate. It has been observed that all household members are usually involved in the preparation of fish for consumption; typically men gut fish, while all other available household members do the cooking. None of the interviewed farmers has ever hired outside labour for aquaculture purposes except those few farmers who hired an excavator driver for digging a pond. However, neighbourly help among farmers is very common.

Table 15: Typical work distribution among household members for aquaculture-related activities

Aquaculture related tasks	Men	Women	Children
Pond preparation	x	x	
Stocking of fish	x		
Collection and application of feed	x	x	x
Collection and application of manure	x	x	x
Harvest fish for household consumption	x		
Harvest fish for sale	x	x	x
Harvest snails, shrimp, crabs and mussels		x	x
Sale of fish on market		x	
Processing of fish, e.g. cooking	x	x	x

5.1.5 Harvest, yields and use of aquaculture produce

Fish from nursery ponds are removed after a certain amount of time and are either transported to one's own grow-out ponds or they are sold to other farms for further grow-out. In grow-out ponds, farmers continuously catch aquatic products for household consumption or when they receive guests; fish, like poultry, are typical "visitor foods". Larger amounts of fish are harvested for sale at the end of the major rearing period. The fish are sold either when they reach marketable size, when money is needed, when farmers have fixed harvest dates with traders or when water shortage or fish diseases force farmers to take action. Large harvests also take place for certain social events such as weddings or funerals. The time of harvest can also partly depend on certain traditions; for example, one family reported that all members of their clan do not harvest any products during a defined time period. In general, only big fish are caught, while small fish are kept in the ponds for further grow-out, and only rarely do farmers harvest all fish at once. The harvest after the main rearing period is referred to as the "final harvest" in the following text. However, some fish remain in the ponds even after this harvest.

The major rearing period usually lasts between one and two years; thus, farmers typically do not have a regular annual income from fish production. During the final harvest, farmers often drain half to three-fourths of the pond water and harvest fish with the use of a seine net. With the use of this method, it is usually not possible to catch all individual fish; mud carp, for example, can disappear in the mud. Provided farmers are able to drain their pond completely, they can collect these fish either with a net placed in the water outlet or fish will accumulate in the depressions on the pond floor, from which the fish can be easily removed. A small net placed in a neighbouring pond or a canal is frequently be used to collect all of the fish. They are later divided according to size and negotiations with traders into two groups: fish for sale and fish for restocking. It is common during big harvests that farmers get help from neighbours and friends. Harvest festivals are often celebrated afterwards and some of the caught fish are eaten together with the helpers. It is also common that farmers give away some of the aquatic products, such as tilapia, as gifts to the participants.

The average yields from farmers' last final harvests were reported to be 1.97 tons ha^{-1} after a mean rearing period of 17 months (~ 1.4 tons ha^{-1} $year^{-1}$; survey 2). Grass carp, the most important species for income generation, usually account for the highest share of the total biomass harvested.

After a certain period of rearing time, farmers begin catching fish for household consumption; for this purpose they use either casting or dip nets. The estimated monthly fish consumption typically ranges between 5 and 10 kg per household (average 7.6 kg). However, farmers often do not remember the exact amounts removed, so this data is based on rough estimations.

Besides cultured species, farmers also harvest naturally entering self-recruiting species, which can include fish such as crucian carp (*Carassius carassius*), catfish (*Clarias sp.*), climbing perch (*Anabas testudineus*) and snakehead (*Channa/Ophiocephalus sp.*) or other aquatic products such as snails, mussels, crabs or shrimp. The latter are usually caught by scouring the pond mud or they are trapped using rice bran as bait. According to farmers' estimations, around 166 kg ha^{-1} of these species are harvested during one production cycle (survey 2). These species are mainly consumed within the households and only a small proportion is sold. Even though tilapia and common carp are often self-recruiting species in farmers' ponds, in this study they are considered as cultured fish. Apart from small aquatic products, higher vertebrates are also caught and consumed. These are creatures whose habitats are located near or within the body of water and therefore include snakes and frogs.

In addition to the harvesting of fish for sale and household consumption, some fish are also sacrificed in rituals. It is a common practice to sacrifice fish at funerals, at certain times after death, after the construction of a new house or during "*Tết*" (New Year). Common carp are typically used in these cases; the fish is cooked, left on an altar for a while and usually eaten afterwards. Some common carp are harvested on the 23rd of December (lunar calendar) as oblation for the so-called "kitchen god" ("*Ông Công*"/"*Ông Táo*"). In some traditional medical rituals, fish also play an important role; for example, tilapia are occasionally sacrificed with the belief that this act can cure people.

Although profit margins are approximately 10% higher when fish are marketed directly, most farmers tend to sell fish to traders, who in turn manage the retail of those fish to consumers. During the last production cycle, grass carp from 69% of ponds were sold to traders, 22% were marketed directly and 6% were sold to other farmers in the village (survey 2). Traders are generally able to buy larger quantities of fish at once, for example, the total produce of a pond. In contrast to farmers, traders own facilities such as cemented tanks with a continuous supply of fresh water, and can therefore keep fish alive over a longer period of time. When farmers choose to market fish themselves, they often have to split the harvest into smaller units, which requires higher time and labour output compared to selling all of the fish at once to traders. On the harvest day, fish are usually caught in the early morning, and traders come directly to the pond site for purchase. They transport and store the fish before retailing them. The Yen Chau traders tend to be men, but their female relatives are in charge of selling the fish at the Yen Chau district market. Some of the fish are also sold to villages in remote areas of the district, which is usually carried out by the male traders themselves.

Every day, 4 to 5 retailers or farmers sell fish at the Yen Chau district market. Fish are usually traded whole and alive, and they are kept in a basin that is partially aerated. Power cuts occur frequently, which makes it very difficult for retailers to keep the fish alive. The big fish (> 1.5 kg) are sometimes cut into pieces and are not kept on ice, just like those that are marketed dead. The hygienic standard on the market can be considered rather low.

According to the traders, a total of 200 to 350 kg of fish is sold on the district market in a given day. They reported that the local demand for fish has increased over the past few years. In the past, fish from the Yen Chau communes were also exported to other districts, and in recent times, all produced fish are sold within Yen Chau itself. The traders stated that local fish alone were not able to cover the market. Therefore, a lowland middleman began to pass through daily to sell lowland fish (e.g. from Ha Tay province) to the Yen Chau market as well as to other districts in the Son La province. In particular, the endogenous production of common carp, mud carp/mrigal/rohu was not sufficient to supply the demand of the Yen Chau market according to local traders.

Fish prices during the study period are shown in Table 16. The highest price is associated with the common carp, which exhibits a relatively stable price of 30 000 VND per kg. This is followed by grass carp with prices ranging between 25 000 - 27 000 VND kg^{-1} during the cooperation period. However, fish prices have increased over the last few years. In 2005, prices for grass carp were approximately 38% higher than in 2003. Large fish generally have more value, which is reflected in a higher market demand and higher prices. Prices of small tilapia are sometimes below 10 000 VND kg^{-1}, while prices can be up to 20 000 VND kg^{-1} for larger tilapia. The sale of small tilapia from farmers' ponds by local fish retailers was generally not observed, as this was usually done by the farmers themselves. In the case of small aquatic products, farmers usually received 4 000 VND for one kg of mussels, 5 000 VND kg^{-1} for snails, 20 000 VND kg^{-1} for crabs and 30 000 VND kg^{-1} for shrimps (state: 2005).

According to the traders at the Yen Chau market, the local people in Yen Chau town prefer the taste of common carp to other fish species, but since its price is comparatively high, they often buy other fish species instead. In the case of silver carp, the origin is often the determining factor in a purchase. When these species originate from a lake, they are valued highly, whereas the ones from ponds have a rather bad reputation.

Table 16: Fish prices on the district market in Yen Chau in VND per kg live fish

	Grass carp	Mud carp/mrigal/rohu	Common carp	Silver carp/bighead carp
18.11.04	25 000	20 000 - 23 000	30 000	18 000 - 20 000
15.01.05	25 000	23 000	30 000	17 000
16.05.05	27 000	20 000 - 22 000	30 000	18 000 - 20 000
15.09.05	26 000	20 000	30 000	n.a.
18.05.06	26 000	20 000	30 000	20 000

n.a. = not available

The fish species that are usually harvested for home consumption are those that are either difficult to sell or that farmers consider to be particularly delicious. For example, grass carp are typically marketed, while tilapia, which fetch comparatively low prices on the market, are frequently consumed within the household. Regarding farmers’ own fish preferences, they often prefer common carp and mud carp/mrigal/rohu over grass carp.

Fish are always eaten fresh and are never processed for storage over longer periods of time. Black Thai farmers tend to eat their fish in different ways. Usually, bigger fish (e.g. grass carp) are cleaned of the visceral parts, put on a stick and barbecued directly in the fire, while smaller fish (e.g. tilapia, silver barb, self-recruiting fish) are often fried in a pan and eaten with their inner organs and bones. Normally, fish heads are used as an ingredient in soups, whereas intestines (cleaned in the case of bigger fish), gonads and air bladder are cooked into a dipping sauce. The consumption of fresh fish meat (e.g. from silver carp) is also typical; it is usually cut into small pieces and eaten together with leaves of native trees.

When fish farmer households (5 individuals) were asked about their average monthly consumption of different animal protein sources, they reported an intake of 7.6 kg fish, 2.1 kg poultry, 3.7 kg meat from large animals and 2 kg from small animals such as worms, insects and small aquatic animals in addition to approximately 17 eggs (survey 2).

In general, farmers produce fish for both income generation as well as home consumption. From the 85 farmers interviewed in survey 2, only two farmers cultured fish exclusively for household consumption and the same number of farmers reported producing only for the market. Fish farmers often consider themselves richer than non-fish producing farmers, and aquaculture is generally seen as a lucrative business. It became obvious during the interviews that fish farming in the past was predominantly subsistence-oriented, whereas farmers now produce fish increasingly for the markets. Farmers (survey 2) reported that their average household income was almost 15 mil VND in 2004, of which approximately 12% was derived from the sale of aquatic products. However, this percentage also considers those farmers who did not sell any fish during the year. When farmers were asked about their main reason for producing fish, 52% of the farmers mentioned that having fish for household consumption is of higher importance than fish production for income generation. The typical argument used by farmers was that they are able to save money, since “they do not have to buy fish on the market”.

5.2 The integrated agriculture-aquaculture system of Black Thai - Linkages between sub-systems

On average, the interviewed fish producing households each comprise 5 members. The mean farm size per household is 1.7 ha; paddy fields account for approximately 11% of this area, ponds for 8.8% and upland fields (maize, cassava, banana and cotton) typically comprise over one ha (survey 2). Fields are usually scattered, consisting of small plots located at different sites that are somewhat far away from the farmers’ houses.

Table 17 demonstrates the amount of the fish farmer households that produce certain crops and animals. In addition, these farmers ranked the different crops and animals produced with regard to their importance for income generation and household consumption. 79% of all farmers considered maize as the most important product for income generation followed by cassava and fish. In the case of household consumption, more than 90% of farmers ranked rice as the highest, and in more than 79% of the cases, fish is placed second (survey 2).

Table 17: Production of different crops and livestock among fish farmers (survey 2)

Produced crops					
Crop	Rice	Maize	Cassava	Fruits/vegetables	Cotton
Occurrence in farms	100%	98%	93%	86%	5%
Animal husbandry					
Species	Poultry	Buffalo	Cattle	Goat	Pig
Occurrence in farms	88%	84%	51%	41%	26%

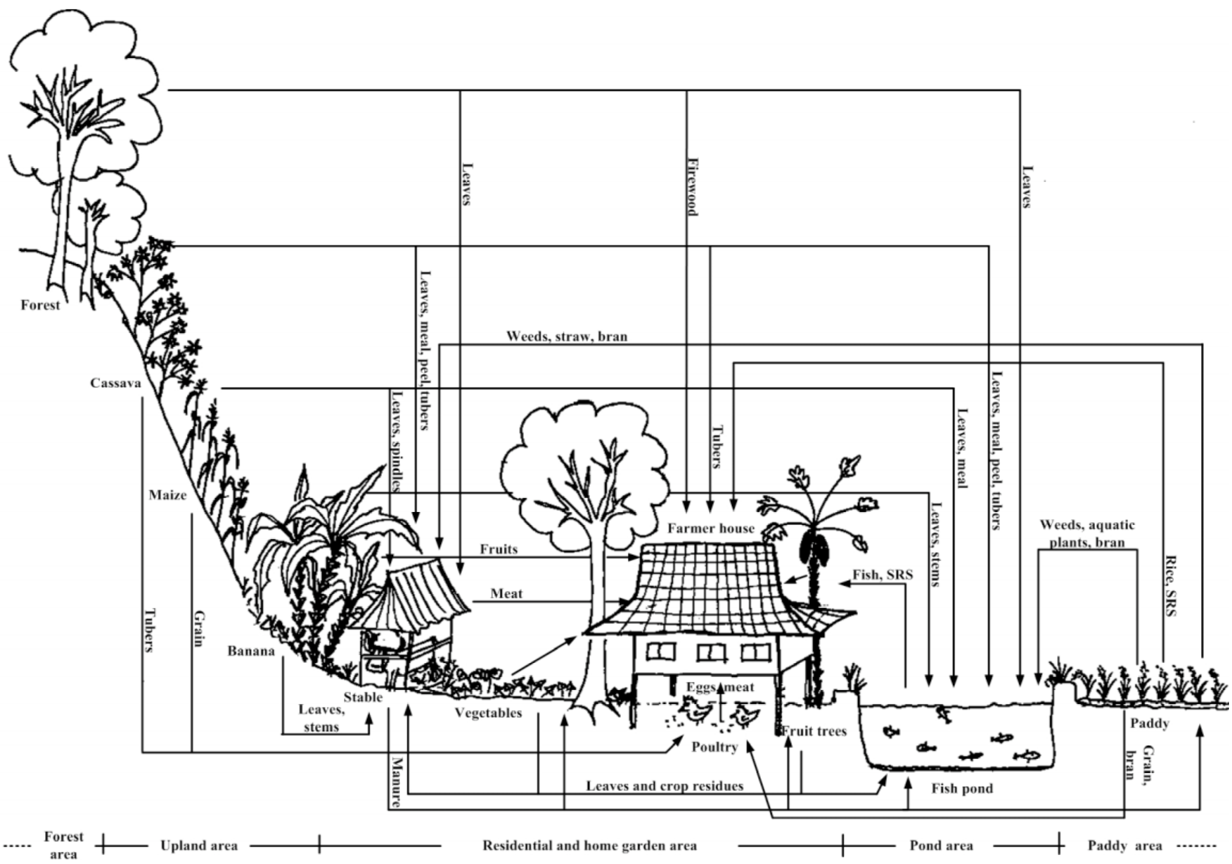
Ponds are integrated into the overall farming system of Black Thai farmers. Figure 16 shows some important resource flows between fishponds and other production units in a typical farm. Usually, the leftovers from one production unit serve as input to other units. In the case of rice, paddy fields and fishponds are closely linked to each other, often through a shared irrigation system, which leads water through paddy fields into ponds or vice versa. Farmers also use weeds, aquatic plants and rice by-products from paddy fields as feed for fish. Straw is also utilized on farms and serves predominantly as feed for large ruminants but is also used to protect soil humidity and is employed as weed control for fruit trees.

According to the cooperating farmers, the mean rice yield was 8 tons ha^{-1} $year^{-1}$ (two crops) in 2005. These farmers reported that of the unprocessed rice grains brought to mill, about 60-70% of this consisted of grain and 30-40% of rice hulls and rice bran. Rice bran is also frequently fed to fish and pigs, whereas rice grain is either consumed by the household or fed to poultry, and only a few farmers sell a surplus of rice (local market price 2005: ~ 2 000 VND kg^{-1}) or exchange it with other farmers. Some farmers also utilize pond mud by extracting it for use as fertilizer for paddy fields and rice seedbeds. It is sometimes the case that farmers use the pond area for producing rice. However, local regulations do not permit farmers to convert a paddy field into a pond without special permission from the district authorities. Nevertheless, it was discovered that some farmers use their paddy fields illegally as ponds.

Paddy rice is usually produced as a double-crop, provided that sufficient water is available. For example, in 2005, the amount of irrigation water was very limited during a certain period of time, so many farmers were forced to produce only a single crop of rice. The time of rice transfer is often regulated on the communal and village levels and is coordinated with the local irrigation authorities; therefore, almost all farmers transfer rice at approximately the same time. In contrast to pond water, an irrigation fee is charged for paddy field areas.

The rice that is cultivated mainly consists of introduced high-yielding varieties, but also local sticky rice varieties are produced. Farmers often consider local varieties to be more delicious, but yields are comparatively low. Seeds are often purchased, but in the case of local rice varieties, farmers may use their own seeds for several cropping seasons. Typical inputs include manure, off-farm fertilizers (NPK, urea) and pesticides. Water usually flows through the fields during the growing season and is often stopped right before harvests. After harvesting the rice, buffalo are let into the paddy fields for grazing and fertilizing the fields. In some of the fields that are located near a water supply, vegetables are planted in the fallow periods. Paddy fields also serve as a source of aquatic products including fish, crabs, snails, shrimp and other self-recruiting species, which are harvested and occasionally sold. According to the cooperating farmers, around 20 kg ha^{-1} $year^{-1}$ of those species are caught in the fields.

Almost all of the interviewed farmers also produce maize in upland fields. Farmers normally use hybrid maize varieties (e.g. "*Lai 10*"), which are planted in April or May in monoculture or partly combined with cassava. There is little to no crop rotation and farmers often apply inorganic fertilizers (NPK, urea) but usually no pesticides. After the maize is harvested in September, the remaining plants are burned. The soil usually remains bare until the coming production season, which presents the hazard of erosion in these upland fields. The majority of the harvested maize is sold to traders, who transport it to the lowlands, where it is sold, for example, to the animal food processing industry. Maize sales often account for the majority of income for farmers. In 2005, the price for one kg of dried grains was ~ 1 900 VND kg^{-1}. Normally, a small amount of maize is stored as poultry feed. All parts of the plants are utilized, as maize leaves are fed to fish and ruminants, maize meal is applied to nursery ponds, dried spindle is occasionally used for cooking and young spindles serve as ruminant feed.



SRS = Self-recruiting species

Figure 16: A topographical cross-section of the land and an example of nutrient flow between different farm activities

Also, the upland crop cassava is produced primarily in monoculture. One's own cassava cuttings or cuttings obtained from neighbours are often planted and the tubers are harvested after several months or years, depending on the variety. The majority of the cassava tubers are sold to traders (price 2005: ~ 1 000 VND kg^{-1}) and only a minor share is fed to animals such as poultry and fish. Cassava leaves and peel serve as fish and ruminant food, whereas cassava meal is applied to nursery ponds. Some farmers reported that they mixed cassava peels together with animal and green manure in a hole in order to turn it into fertilizer for paddy fields. Sometimes, cassava is cooked together with sticky rice, but within the household, it is typically used for the fermentation and distillation of cassava liquor. Cassava stems are also used for cooking purposes.

Banana is also produced in the upland fields or in home gardens. Banana blossoms and fruits are used for household consumption or are sold. Leaves are considered an important feed source for ruminants and fish. Banana peel is frequently fed to ruminants, and hashed banana stems are fed to ruminants, fish and pigs.

Fruits and vegetables are typically produced in home gardens and 36% of the interviewed farmers use pond water for irrigation of those gardens (Survey 2). Fruits and vegetables are used for household consumption as well as pig feed, and the surpluses are commonly marketed. Some common fruits produced in the region comprise mango, longan, litchi, tamarind, papaya, pomelo; typical vegetables are morning glory, water dropwort, sweet potato, eggplant, cabbage, kohlrabi, lettuce, onion and chilli among others. Sometimes, fruit trees are planted around ponds; thus, ripe fruits may fall into the water and can be eaten by fish. Surpluses that are not consumed by the farmers and that cannot be sold are fed to the farm animals; for example, leftover mango is fed to pigs and ruminants, and morning glory leftovers are given to fish. Kitchen wastes are also given to pigs, poultry, fish, dogs and cats.

5% of the interviewed fish farmers additionally produce cotton in a contracted farming scheme with a Hanoi-based cotton factory. The cotton company provides seed, fertilizer and pesticides and purchases the cotton after its harvest. Bamboo trees are often planted near ponds. The leaves of these trees are fed to ruminants and fish, and the stems are used for construction purposes, e.g. for the construction of feeding rings in the ponds. Bamboo sprouts are either consumed within the household or sold at the markets. Additionally, mulberry trees are found in the region, whose leaves can be fed to silkworms, ruminants and fish.

Some of the interviewed farmers reported that they also manage a plot of forestland as part of their participation in a governmental project. The government provides small trees and supports the foresters with a certain amount of money for planting and taking care of the trees during the first few years. When the timber is lumbered, farmers receive a share of the yields. In general, timber plays an important role in the construction of traditional Thai houses. Forests provide leaves, which are occasionally harvested and fed to fish or ruminants, and they also provide firewood for cooking. Even though it is officially banned, farmers also use the forests for hunting wild animals.

It has been observed, that some farmers keep bamboo stems and timber in fishponds over longer periods of time. The purpose of this is to remove potential insects from the wood and to make the timber more elastic, so that it can be used for various purposes such as house construction.

Chickens and ducks usually scavenge around the farmsteads and are additionally fed rice, small pieces of cassava roots, maize, rice bran as well as kitchen waste. Poultry and eggs are typically consumed within the household, given away as gifts or sold at the local market. According to the interviewed farmers, poultry is easily affected by disease and the mortalities of these animals are relatively high. In all case study farms, poultry mortalities occurred during the cooperation period. Frequently, recurring bird flu (H5N1) cases in Vietnam led to a temporary embargo on the sale of poultry products.

Ruminants are often fed grass, leaves or straw. Usually, feed is either collected and brought to the animal pens or ruminants are led to fallow areas (e.g. harvested stubble fields) or communal grazing lands. Large ruminants supply calves that can be sold, draught power, manure and meat and have the additional importance of demonstrating the social status of the farmer. In the case that fodder is limited for feeding both fish and large ruminants, priority is usually given to the latter. Goats also provide offspring and meat, which fetches a relatively high price at the local market (~ 30 000 VND kg^{-1} live weight). While herding and watching over ruminants is often carried out by elderly people or children, women usually take care of poultry and pigs.

Typically, local "*Ban*" pigs or introduced varieties are reared and fed vegetables, kitchen waste, rice bran, maize, cassava and purchased concentrated feed. In most of the interviewed farms, no pigs are produced, since feed, labour input and investment costs (e.g. from the construction of pens) as well as susceptibility to disease are considered to be too high. In addition, certain pig feeds have to be cooked, which consumes additional firewood.

Some farmers produce silk from silkworms fed on mulberry or cassava leaves. The worms themselves are either consumed within the households or sold. Other less frequent animals raised in this region include pigeons, rabbits, dogs and guinea pigs, all of which are used for meat production.

The manure from ruminants and pigs is normally applied to paddy fields or home gardens, whereas a smaller share is applied to fishponds. Since manure is a limited resource, farmers are forced to budget it and usually give priority to their crop fields instead of fishponds. Nightsoil is usually mixed with cooking ash and serves as fertilizer for rice fields or home gardens. Cooking ash is additionally utilised as pest control for crops.

Typical farming activities and the fish feed they provide over the years can be seen in Figure 17. Normally, peaks in labour occur from February to November. This starts with transplanting the first crop of rice (February), followed by hand-weeding the paddy fields, soil preparation and seeding the maize fields (around April). Then, further weeding of upland and paddy fields takes place followed by the harvest of the first rice crop in June. After that, it is time for the transplantation of the next rice crop, followed by weeding and the harvest of maize in September. This finally ends with the harvest of the second rice crop in November. Farmers also usually devote more time to fish farming during the hot and rainy season as compared to the cold and dry season, when grasses and leaves are limited and fish eat less.

When the high summer workloads lead to limited labour resources, farmers prefer to spend their manpower on crop production or production of other livestock rather than fishpond-related activities.

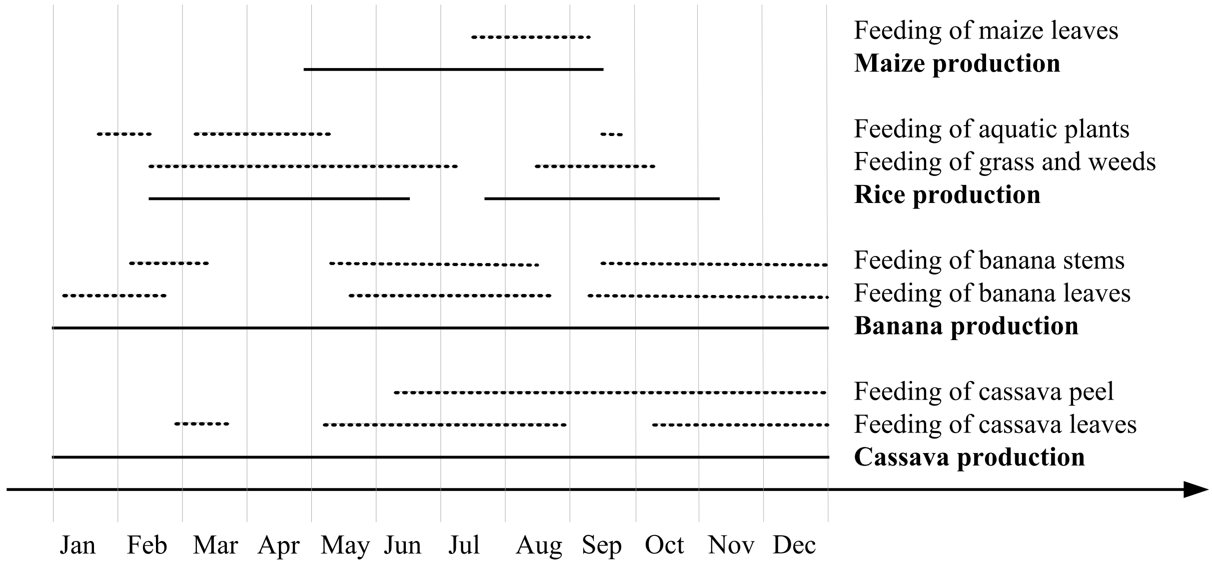


Figure 17: Farming activities of a typical farmer and the feed applied to his fishpond over a year (data gathered from case study farm CK2; year 2005)

In those households where three generations live together, it has been observed that the younger people usually work in the fields, while the elderly take care of livestock and fish. In 47% of the interviewed households (survey 2), at least one member usually works off-farm. Most farmers stated that off-farm jobs are available in the region but the reason for not accepting them is often the lack of time. Temporary jobs usually pay daily salaries ranging between 15 000 and 30 000 VND. The different on- and off-farm resources for a farmer's household are shown in Figure 18.

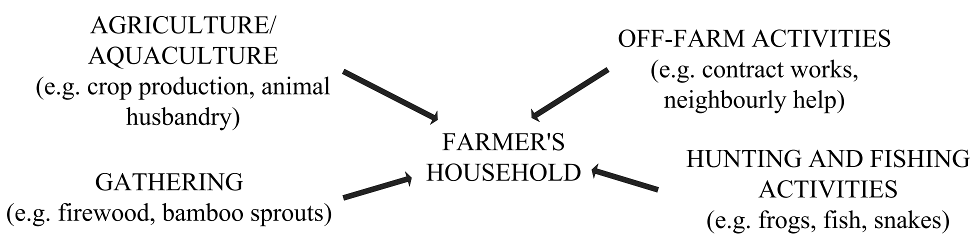


Figure 18: On- and off-farm resources for a farmer's household

5.3 Limitations and problems of local fish production

It has already been mentioned that farmers consider aquaculture production to be a lucrative business. However, it became obvious during the interviews that farmers are not satisfied with the current output of their ponds and they seek measures to improve productivity. In order to evaluate the bottlenecks of the current system, the farmers were asked to assess the impact of potential problems of their fish production (survey 2). The results are presented in Figure 19. While fish disease and theft are considered big problems, predators and limited access to pond inputs are of minor importance.

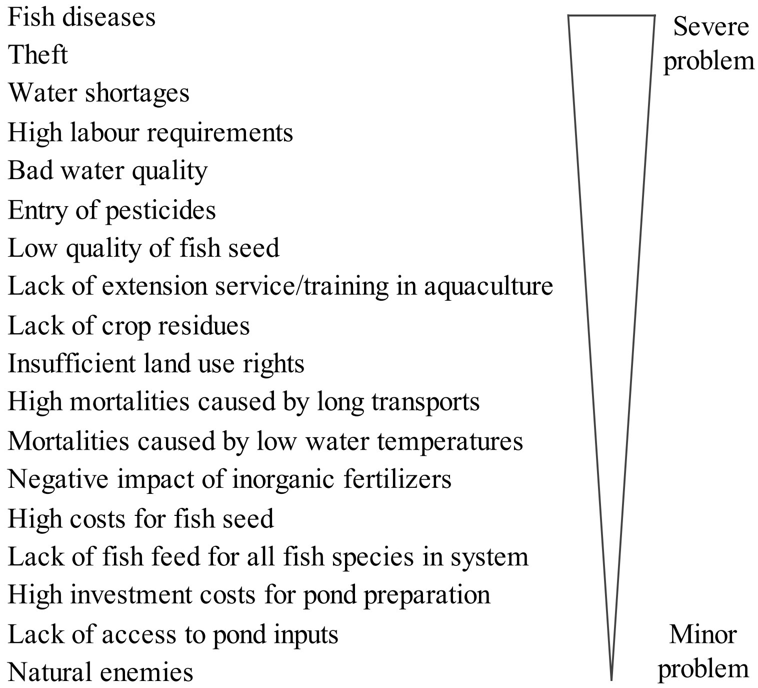


Figure 19: Ranking of potential problems in fish farming (survey 2)

5.3.1 Fish diseases and mortalities

The main constraint in fish production according to the interviewed fish farmers and village headmen are diseases affecting grass carp, which frequently lead to considerably high fish mortalities. Disease outbreaks were observed from 1996 onwards and usually occur from March to November with a peak during the hot and rainy months. The disease(s) affect fingerlings as well as adult fish and lead to external symptoms such as the loss or easy removal of scales, dark colour, swollen ventral part and red spots on the body. Also, internal bleeding has been observed in some of the affected fish. Haemorrhages, skin lesions and the blackened bodies of grass carp are shown in the photos, Figure 20. Affected fish usually stop feeding, swim sluggishly and separate from the others near the surface and die some days after the appearance of the first symptoms. Considering all 155 interviews, around 70% of fish farmers had to cope with grass carp mortalities in previous years. Some farmers reported the loss of their entire stock. Those interviewed farmers, who could assess the amount of fish affected during the last production cycle, reported a loss of an average 40 kg of grass carp per pond (survey 2), which corresponds to approximately 1 mil VND in monetary terms. Also, in six of the nine case study farms, grass carp disease(s) occurred during the cooperation period. The disease(s) is/are unknown to farmers and researchers and cannot be named here.

Figure 20: External disease symptoms of grass carp (from left to right): Haemorrhages, skin lesions, blackish body

Farmers consider limited water quality, transmission of germs from one pond to the next and bad quality of fish fry as possible reasons for the occurrence of grass carp disease. However, grass carp mortalities occur in ponds located in the uplands as well as in ponds located in the valleys. In the cases where several ponds are located next to each other, it occurred that only some of the ponds become affected. Table 18 shows the time of appearance as well as the disease symptoms, feed applied and water parameter measured during the period of grass carp disease in six farms in Bat village.

The typical initial reactions of farmers after the appearance of fish disease include the partial exchange of pond water, reduction of the feed and manure supply and the sale of weak fish. Some farmers reported that they apply certain plant leaves, such as Siam weed (*Chromolaena odorata*), wild basil (*Ocimum gratissimum*) and chinaberry (*Melia azaderach*), which they claim promotes fish health. Some farmers also apply lime if they have access to it. In general, the techniques applied by farmers in order to effectively prevent diseases or cure fish have failed so far. In order to avoid the risk of losing fish, some farmers stopped the production of grass carp or changed the species composition in favour of other species.

However, most farmers continue rearing grass carp, since this species is considered to have a good growth potential and is easy to market at high prices.

Diseases also occur among other fish species, such as common carp, but to a much lesser extent. In the case of non-grass carp species, no outbreaks of diseases were observed during the study period. The nursery/hatchery Yen Chau, however, reported the frequent occurrence of fish infected with fungi at the beginning of the nursing season.

Table 18: Selected parameters recorded in six farms of Bat village during the period of grass carp disease

Time of occurrence	Size of GC affected and external symptoms	Feed supply at the time of disease occurrence	Selected water parameters measured during the period of diseases
Aug/Sept 2004	300 – 900 g; blackish colour, easy loss of scales, fish swim sluggishly at the water surface, stop feeding	Banana, cassava and maize leaves, aquatic plants	Greyish-olive colour, SDD: 15 cm, DO: 9.7 mg l^{-1}, T: 33.2°C, pH: 8.0 (20th of August 5 p.m.)
Nov 2004	300 – 400 g; red spots, easy loss of scales, blackish colour, fish swim near the surface, stop feeding	Manure, banana leaves, rice stems and rice bran	Clear water, shallow pond, DO: 6.7 mg l^{-1}, T: 24.6°C, pH: 7.8 (20th of November, 4 p.m.)
Aug 2005	1 500 – 1 800 g; blackish colour, easy loss of scales, swim at surface*	Maize, banana and cassava leaves, weeds and little aquatic plants	n.d.
Sept/Oct 2005	300 – 1 000 g; blackish colour, fish swim sluggishly at the water surface, stop feeding	Banana and cassava leaves, weeds from paddy fields, rice bran	Reddish-brown colour, SDD: 26 cm, DO: 2.8 mg l^{-1}, T: 26.1°C, pH: 7.6 (16th of September; 8 a.m.)
Sept/Oct 2005	200 - 1 500 g; blackish colour, easy loss of scales*	Cassava and banana leaves, weeds, buffalo and pig manure	DO: 3.4 mg l^{-1}, T: 24.2°C, pH: 7.6 (27th of October; 7.20 a.m.)
Oct 2005	500 - 1 500 g*	Banana leaves, weeds and little aquatic plants	Dark green colour, DO: 3.1 mg l^{-1}, T: 23.3°C, pH: 7.5 (27th of October; 7.20 a.m.)

DO = Dissolved oxygen; GC = Grass carp; SDD = Secchi disk depth; T = Water temperature; n.d. = not determined; *data base on observations by farmers

5.3.2 Theft

Theft of fish is a widespread problem in the study area and occurs especially in those ponds that are located far away from the farmers' houses. Over the study period, fish were stolen from two of the case study ponds (SV2, VL3). In order to protect fish, tree branches are put into ponds to bar thieves from angling or netting. Another means of avoiding theft is staying overnight at pond sites. In the case of larger ponds, some farmers construct small cottages at the pond location, where some of the household members stay during the major rearing period, which was the case in an upland pond belonging to case study farm SV2.

5.3.3 Water shortages

Available water resources can become scarce, especially during the dry season. Water availability in the Chieng Khoi commune usually reaches its lowest point between April and May, when the reservoir lake is almost empty and paddy fields require high amounts of irrigation water. The effects of water shortage can be illustrated by describing a particularly dry year. In 2005, the lack of water from both the reservoir and precipitation was very severe and farmers had to postpone all planting activities. Usually, when paddy fields are first irrigated and water is distributed among fields and ponds, local irrigation authorities give priority to paddy fields, which may lead to the discontinuation of water supply to ponds. In combination with the limited rainfall in 2005, this led to an enormous decrease in the water level in several of the ponds and consequently to a negative impact on the fish. Farmers reacted by searching for new water sources and changing the streamlines by creating new pipes or water trenches. In severe cases, farmers were forced to prematurely sell fish. Some of the ponds that are usually permanently stocked could only be used during the time of year when water was plentiful. It could be observed that several farmers with access to tap water used this for pond-related purposes, an activity which is not permitted by local water management authorities. Temporary water shortages in ponds frequently occur and can be caused by various factors including the repair or construction of new irrigation canals or other changes in the flow channels. Interruptions of water flow in the case study ponds, for example, were usually imposed upon farmers and only rarely in their interest.

5.3.4 High labour requirements

Farmers often mention the high labour demand of collecting fish feed and manure. Typically, farmers spend around two hours per day during the rainy season just for the collection and transportation of fish fodder (survey 2). However, in some cases, aquaculture activities can be combined with other farming tasks. Thus, the weeding of paddy fields simultaneously produces food for fish and removing pond mud creates fertilizer for crop fields.

5.3.5 Limited water quality

In this survey (survey 2), farmers were only asked if they consider the limited water quality as a severe problem in their ponds. Factors that signify limited water quality include turbid water and fish gulping at the water surface in the early morning, indicating a low dissolved oxygen level in the ponds. It has been observed that farmers who were afraid of losing fish due to insufficient DO reacted by stirring the water with a tree branch or going into the pond themselves and moving around.

Since ponds are integrated within the overall irrigation system, farming and household activities may also influence the water quality in the ponds. Potential contributors to water deterioration can include the entry of sediments, detergents, inorganic fertilizers as well as pesticides (see following chapter).

With heavy precipitation, sediment from eroding upland fields as well as from the surroundings of water-supplying streams and canals can enter into the irrigation system. Erosion particularly occurs in those times when maize is not yet planted or the plants are still small so that most of the soil is bare. This erosion and subsequent entry of sediment usually leads to turbid and reddish brown-coloured pond water.

The washing of the body and clothes often takes place in ponds as well as in water-supplying streams and canals. Almost half of farmers reported taking baths in their ponds and 25% of the farmers use this water to wash their clothes (survey 2). The use of industrial shampoo and washing powder is common. However, most of the interviewed farmers do not see any problems affecting their fish caused by soap residues.

Leftover feed from cassava and banana are regularly removed from the pond surface. However, not all residue can be collected; thus, some of this can accumulate on the bottom of the pond. In some ponds in the study area, bubbles that smelled like hydrogen sulphide were observed, which indicates anaerobic conditions in the pond mud.

Furthermore, it has been observed that buffalo also bathe in the ponds. In these cases, the pond water becomes highly turbid and, in some instances, the dams even got trampled down.

5.3.6 Entry of pesticides

Farmers typically apply pesticides to cotton as well as paddy fields. Since paddy fields and ponds are often closely linked, pesticides might enter not only via the water-flow and leaching, but also with the weeds and aquatic plants that are frequently collected from those fields and used as fish feed. The concentration of the insecticide fenobucarb in duckweed samples was collected before and some hours after its application by a farmer in his paddy field; this is shown in Figure 21. Even though many farmers are aware of this and try to avoid feeding these plants directly after spraying, they often collect these feeds from shared irrigation canals and therefore can not determine whether pesticides were already applied to those feeds. Typical pesticides applied in the region are summarised in Table 19; "Padan" and "Ofatox" are the most commonly used pesticides according to the interviewed farmers (survey 2). Typically, farmers spray three times per crop (1st application before blooming, 3rd application before formation of grains). Where it is possible, farmers usually stop the water flow for at least one day after pesticide application.

Farmers also consider rats to be a big problem in rice fields. In some villages, all farmers are requested to raise cats for the purpose of catching rats. Even though it is officially banned, some farmers still use prohibited Chinese rodenticides, which farmers consider highly poisonous, since cats and dogs may die after their application. Since these toxins are sold on the black market, people are usually not willing to provide more information about their use.

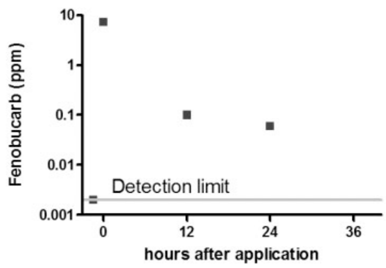


Figure 21: Concentration of fenobucarb in duckweed before and after its application by a local farmer (technique of analysis: PTN 14-DLF carried out by Plant Protection Department, Hanoi)

Table 19: Typical pesticides used by farmers in 2005 (information from local wholesaler)

Trade mark	Active substances	Use	Typical pests
Ofatox	Fenitrothion 20 % Trichlorfon 20 %	Insecticide	Stem borer/Rice seed bugs
Padan	Cartap 95%	Insecticide	Stem borer
Vibasa 50 ND	Fenobucarb min 96%	Insecticide	Stem borer
Hinosan 40 EC	Edifenphos min 87%	Fungicide	*Pyricularia oryzae*
Kasai	Phthalide 20% Kasugamycin 1.2%	Fungicide	*Pyricularia oryzae*
Purion 40 EC	Edifenphos	Fungicide	*Pyricularia oryzae*
Viben C	Benomyl 25% Copper chlorine water 25%	Fungicide	*Xanthomas oryzae*
Vivadamy	Validamycin min 40%	Fungicide	*Pyricularia oryzae/Rhizoctonia solani*

In the survey on pesticides, 27 of 30 farmers reported using pesticides frequently (73% of farmers interviewed in survey 2). Some farmers noted that there is currently a decreased number of pollywogs and leeches in water bodies compared to earlier times and attribute this to the application of pesticides. Several training sessions on IPM were held in the region and half of the questionnaire-interviewed farmers are aware of this technique, but the spraying of pesticides before or after the occurrence of pests is usually used without the consideration of other means of combat.

With the survey on pesticides, it was tested whether an obvious correlation exists between pesticides and the before-mentioned grass carp mortalities. 22 out of the 30 farmers interviewed about pesticides reported frequently occurring grass carp mortalities in their ponds. From the 8 ponds that were never affected, water from paddy fields never made contact with the water from 6 of the ponds. However, in 6 of the affected ponds, mortalities occurred although pond water did not flow through the rice fields first. Grass carp mortalities also occurred in ponds where weeds or aquatic plants from paddy fields were not used as feed. 12 out of 30 interviewed farmers believe that pesticides harm their fish, while 10 farmers do not believe that pesticides have an impact on fish health.

5.3.7 Insufficient quality of stocking material

Some farmers as well as the hatcheries' staff reported a decrease in growth performance of fish over the past decades and attribute the increased occurrence of fish diseases to the low quality of fish seed. The main source of fish in the region is the hatchery in Son La town. According to the hatchery operators, the first broodstock came from this province; in the following years, it was supplemented by large fish from the farmers that were used as spawners. So far, no broodstock has been obtained from outside of the region. Since all broodstock fish of a certain species are kept together and crossed without considering their degree of relationship, inbreeding between first-grade relatives is possible. An inbreeding depression may be confirmed by observations of the hatchery owners, who report frequent high amounts of abnormal fish among offspring. A further problem comes from the discontinuous supply of fish seed from hatcheries, which forces farmers to adapt their stocking management to fish availability instead of time availability and management practices.

5.3.8 Lack of extension service/training in aquaculture

Another constraint perceived by farmers is that the local extension service in Yen Chau has no expertise in the field of aquaculture. In the case that problems arise, farmers often discuss these with their neighbours. However, they lack deep or insightful technical knowledge and often try to find solutions themselves. Other sources of knowledge include fish traders, farmers' unions, hatcheries and mass media.

5.3.9 Low water temperatures

Some of the stocked species cannot tolerate the low water temperatures in the wintertime. Due to this, mortalities of tilapia, catfish and pirapitinga have been observed during the study period.

5.3.10 Natural enemies

Predators are not considered a very large problem in this region. Some farmers mentioned such predators as kingfisher, water rats, snakes as well as predatory fish, (e.g. snakehead), which can be harmful for smaller fish. To avoid the entrance of bigger unwanted fish into the fishponds, bamboo sticks or mats are placed in the in- and outlets of the pond.

5.3.11 Floods and heavy rain

The problem of "floods" was not provided to farmers for ranking. However, flooding occurs frequently, which can result in dykes breaking and fish escaping. This was observed twice during the study period. Farmers try to prevent problems caused by flooding by regularly repairing dykes as well as the in- and outflow fences. Heavy rainfall can also create problems, as fish mortalities were observed directly after their occurrence.

6 Results: The pond system (micro level)

6.1 In-depth case studies: Short description of the case study farms and ponds

All household members of the case study farms belong to the ethnic minority Black Thai, live in traditional Thai stilt houses, have electricity and access to drinking water and do not own refrigerators, but tend to have televisions and some even have karaoke equipment. All case study households own at least one motorbike, with which they can reach Yen Chau town in maximally 15 minutes provided that the roads are passable, which is often not the case during the rainy season.

The sizes of the six farms considered on the micro level vary between 1.4 and 2.4 ha. In 2004, the annual household incomes ranged from 8 to 25 mil VND; on average, 17% of the income was derived from fish sales. The farmers owned an average of 2.5 ponds; the sizes of the investigated ponds varied between 533 and 1 347 m^2 in size and 1.08 and 1.54 cm in depth. In the following, a short description of these farms and ponds is given. Important characteristics of all nine case study farms and their respective ponds are summarized in the Tables 20, 21 and 22.

6.1.1 Short description: Case study farm and case study pond CK1

The household of CK1 consisted of 5 members, including the head of the household, who was the cooperating farmer, his wife and three daughters. The cooperating farmer had been born in 1962, he was the head of the farmers' union and was well-informed regarding important farming activities in the village. The daughters still attended school, but helped regularly at the farm.

The investigated pond is located next to the farmer's house and is supplied with water by means of the irrigation system from the Chieng Khoi dam as well as precipitation. Water enters via a small irrigation canal, is led into the pond through a bamboo pipe, exits into a neighbouring pond and then re-enters the canal. The drainage of the pond leads to a discharge of pond water into the adjacent pond; see Figure 22. The outlet is located below the water surface. In September 2005, large fish were harvested and sold to traders, and in the following months, additional fish were stocked for further grow-out. The time schedule of stocking and harvest activities is shown in Figure 23.

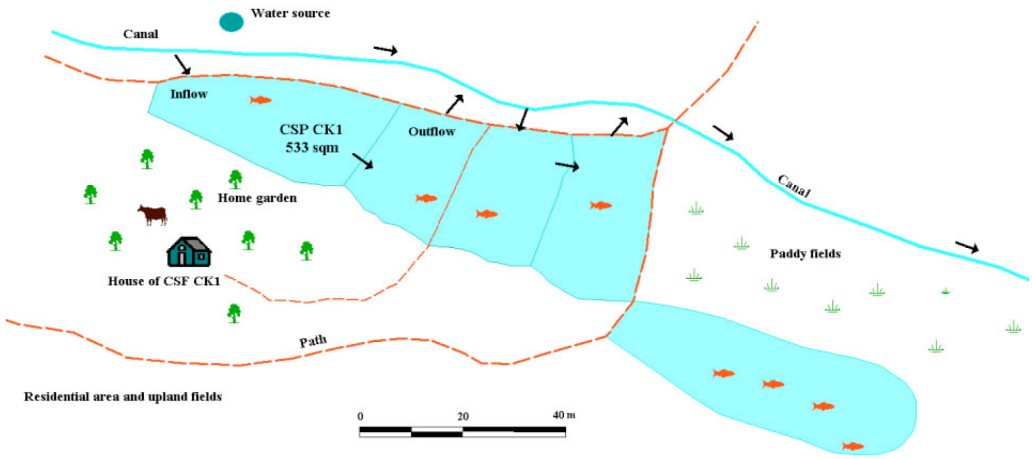


Figure 22: Sketch of case study pond (CSP) CK1

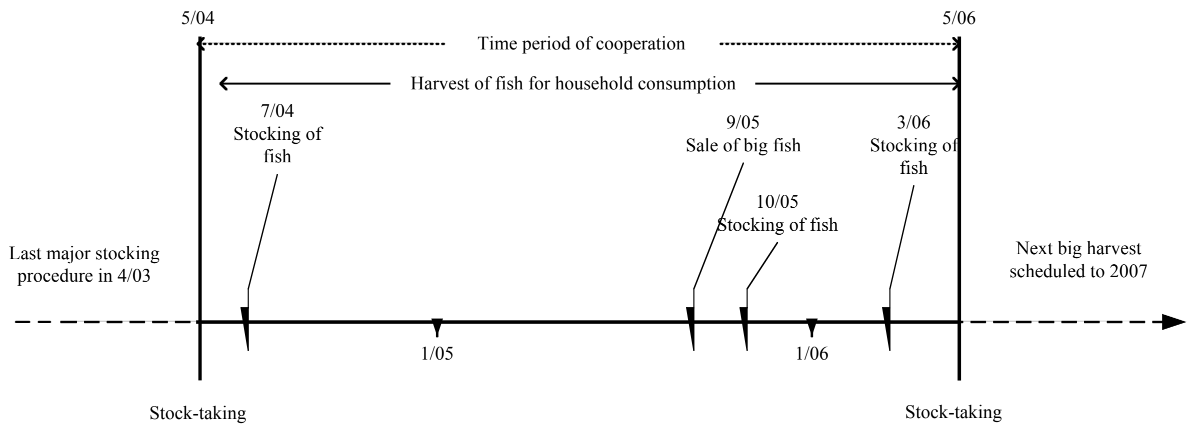


Figure 23: Fish stocking and harvest of pond CK1 during the cooperation period

6.1.2 Short description: Case study farm and case study pond CK2

The household was made up of 6 members, which included the head of the household with his wife, two children and his parents. The cooperating farmer was the father of the household head. During the time of cooperation, he lived separately from his son's family in a small house next to the investigated pond. The cooperating farmer had been born in 1945; he and his wife cared for the livestock and fish, while the younger generation worked in the field. The cooperating farmer had been a soldier during the American-Vietnamese War, was injured during this time and became an invalid.

The water for the investigated pond is provided by a canal that supplies water from the Chieng Khoi dam and by precipitation. During the study phase, the farmer could not always obtain enough water from the canal in order to maintain a continuous water flow through his pond. The water supply depends on the activities in the paddy fields, which leads to a lack of pond water during the rice harvest and fallow periods. In general, the pond is completely drainable, but drainage is connected to the current state of the paddy fields. Since the water from the canal flows directly into the pond, the farmer can not stop the water flow temporarily, especially after heavy rainfall, which is demonstrated in a sketch (Figure 24).

Before the beginning of the cooperation period, the pond area was used for one season of paddy production, and rice was harvested in June 2004. Afterwards, the dykes were repaired and fish were stocked one month later. No mud was removed at that time. The time schedule of stocking and harvesting operations is shown in Figure 25. Farmers harvested the fish from the pond after the completion of the cooperation period in October 2006. Afterwards, they removed the pond mud and increased the pond size (information gathered after completion of the study period).

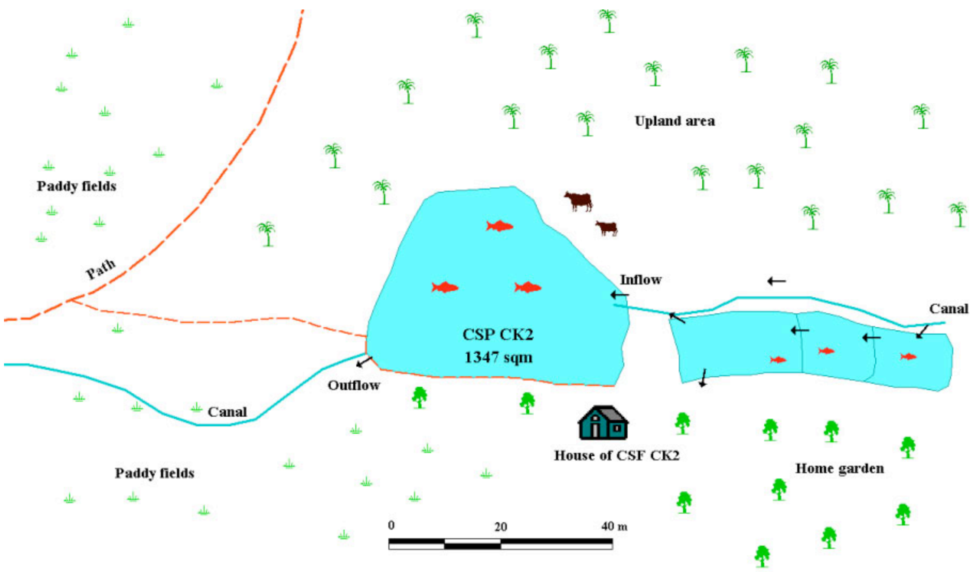


Figure 24: Sketch of case study pond (CSP) CK2

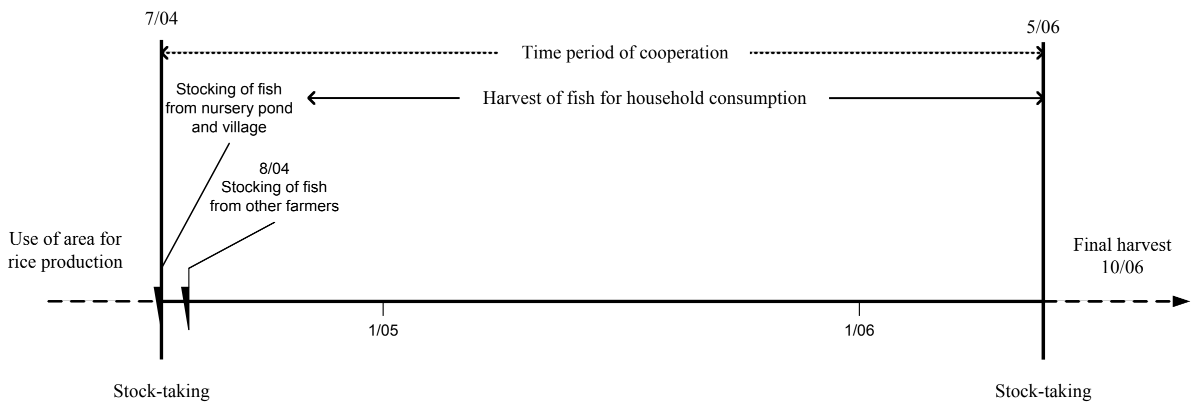


Figure 25: Fish stocking and harvest of CK2 during the cooperation period

6.1.3 Short description: Case study farm and case study pond SV1

The household of SV1 was made up of 5 members, which included the household head, who was the cooperating farmer, his wife, two children and his father. The cooperating farmer had been born in 1962, and at the beginning of the cooperation period, he had the role of village headman, and at the end, he was head of the farmers' union in Bat village. His wife was a teacher in Yen Chau town but worked in the area bordering Laos and was only at the farm on weekends. At some point during their careers, teachers from Yen Chau are requested to work in remote areas for a 3-year period. The children still attended school but helped on the farm after school and on weekends. The father of the cooperating farmer also worked on the farm, as he was in charge of taking care of livestock. During the week, the cooperating farmer took care of the fields and fishponds, cooked for the family and carried out his responsibilities as village headman. He eventually resigned his position as village headman, since he had no time available for these duties.

The investigated pond is located next to the farmer's house and is used for growing out fish up to marketable sizes. Usually, bigger fish are purchased from other farmers, fattened and are already sold after a relatively short rearing period. The pond has a continuous water-flow most of the time during the year, where the water originates from a spring and flows through several ponds before entering the study pond via a bamboo pipe. The water that exits the pond flows out into the paddy fields. Farmers are not able to drain the pond whenever they want, since this depends on other farming activities in the adjacent fields. A sketch of the pond is shown in Figure 26.

Before the cooperation period started, farmers harvested large fish, kept small fish in a deeper part of the pond and dried out the remaining water in the bottom of the pond. In July 2004, they stocked additional fish and raised them together with those kept from previous years. Stocking and harvesting activities of SV1 are shown in Figure 27. Large fish were harvested after approximately 15 months of rearing time. The harvest took place over several days and fish were directly marketed by the farmers. Every 3-4 years, the farmers remove the pond mud and apply it to the rice as fertilizer.

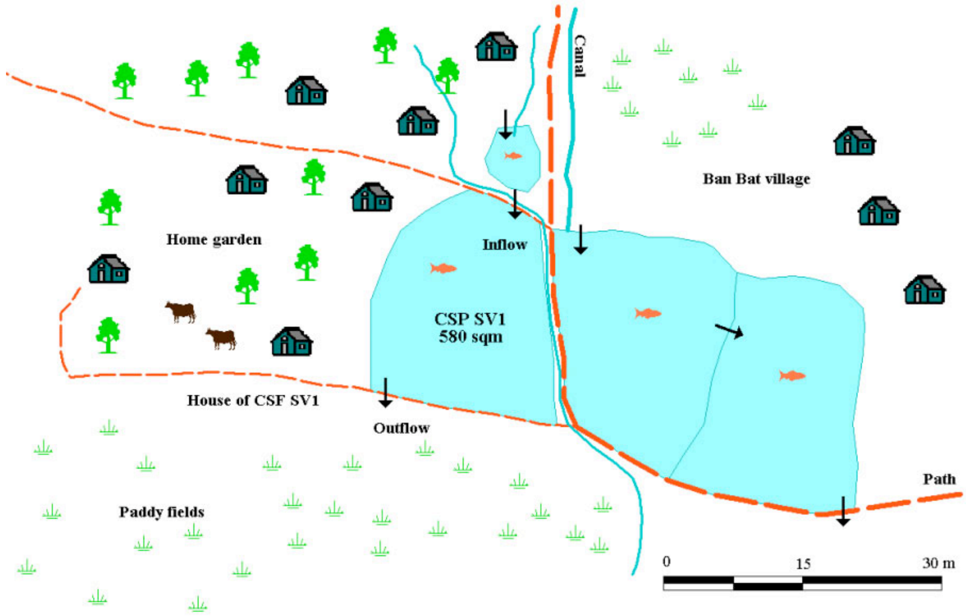


Figure 26: Sketch of case study pond (CSP) SV1

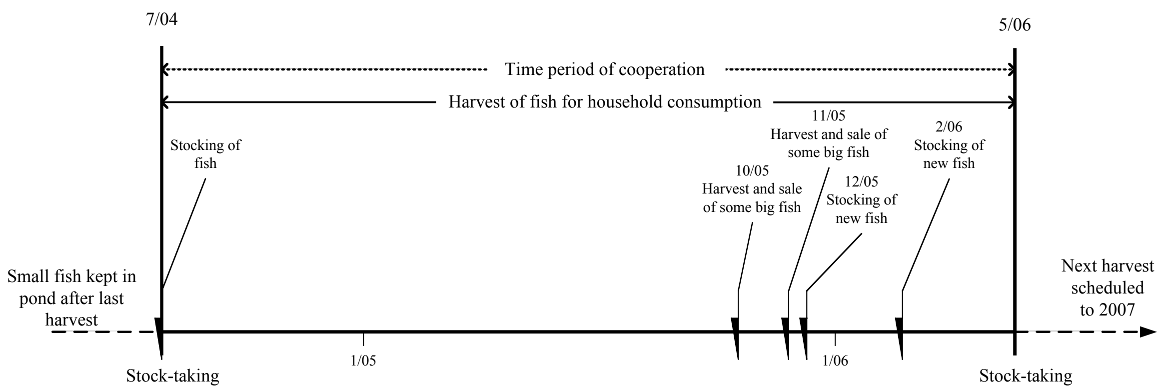


Figure 27: Fish stocking and harvest of pond SV1 during the cooperation period

6.1.4 Short description: Case study farm and case study pond SV2

The household head was the cooperating farmer; he had been born in 1980. The household consisted of him, his wife, daughter and parents-in-law. The elder generation lived somewhat close to a remote pond and mango field that they took care of in order to prevent the theft of fish and for the protection of the fruit. In contrast, the household head and his wife were in charge of the other two ponds and the remaining crop fields.

The investigated pond is located near other ponds and paddy fields at a distance of approximately 200 m from the farmer's house. The pond water originally comes from the Chieng Khoi dam and flows through paddy fields before entering the pond. There is also a subterranean water source on the pond bottom; therefore, the farmer is not able to completely drain this pond. Sometimes, pond mud is removed and used for vegetables that are grown on the pond embankments. The position and shape of the pond is shown in a sketch, Figure 28. The pond was stocked at the beginning of the cooperation period (July 2004) and some large fish were harvested about 15 months later. The major stocking and harvesting activities during the cooperation period are presented in Figure 29.

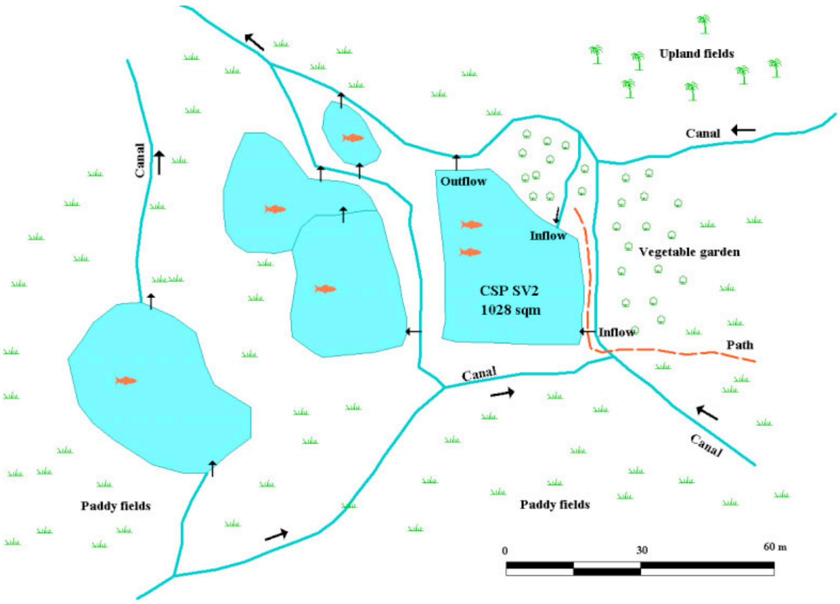


Figure 28: Sketch of case study pond (CSP) SV2

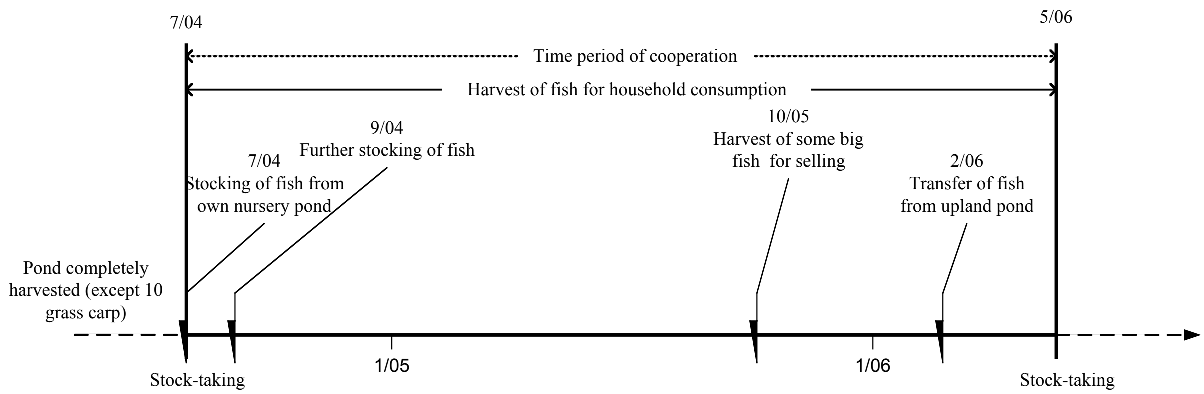


Figure 29: Fish stocking and harvest of pond SV2 during the cooperation period

6.1.5 Short description: Case study farm and case study pond VL1

At the beginning of the cooperation period, the farm VL1 was made up of 5 members, the household head who is the cooperating farmer, his wife, a daughter, a son and his father.

A while later, the father died and the son left the household after he got married. According to the tradition of the Black Thai, after a wedding, the young men will live for some time in the house of their new wives. The cooperating farmer had been born in 1967. He was the vice head of the village.

The investigated pond was constructed in 2000, at which time, a by-pass was made for the stream water, the pond was dug and a dyke was created. The whole project was done by hand during a one-month period. The pond water originates from a spring and flows through a stream and a pond before entering the case study pond; see Figure 30. The pond is relatively deep and pond mud had never been removed. Most fish in this pond were already stocked in April 2004; the stock was surveyed at beginning of the cooperation period in August 2005. After the cooperation period was finished, farmers sold all of the large grass carp and kept the remaining fish for further rearing. Figure 31 shows fish stocking and removal during the cooperation period.

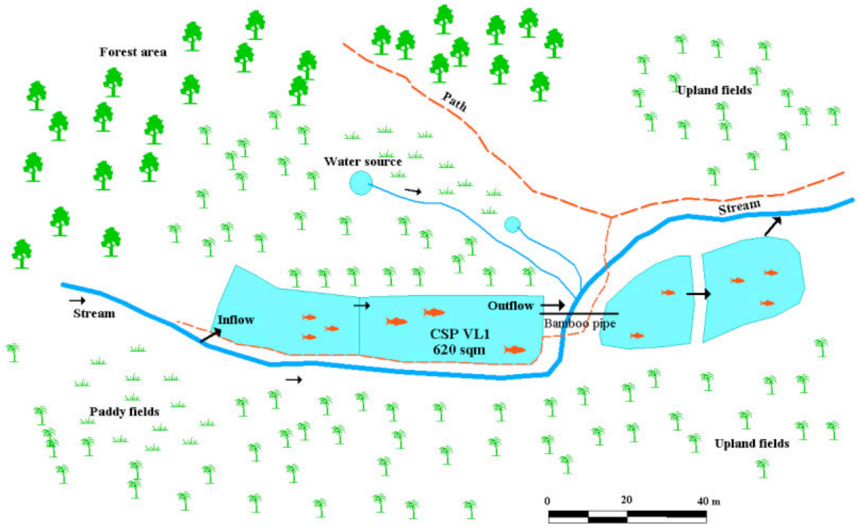


Figure 30: Sketch of case study pond (CSP) VL1

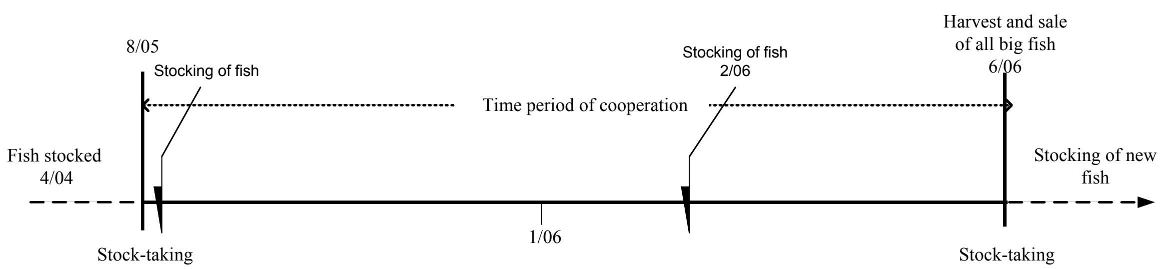


Figure 31: Fish stocking and harvest of pond VL1 during the cooperation period

6.1.6 Short description: Case study farm and case study pond VL2

The household of the farm VL2 was made up of 4 members; this includes the household head, who was the cooperating farmer and had been born in 1962, his wife and two sons.

The investigated pond is supplied with water from a stream, which is let out into an adjacent pond; see sketch, Figure 32. The pond was harvested in August 2005 due to an outbreak of grass carp disease. The larger fish were sold while the smaller fish were transferred to another pond. Water from the pond was released, mud removed, dykes repaired and the bottom was partly dried out. The pond can not be completely dried due to a subterranean water source. In the beginning of October 2005, fish were re-stocked and additional fish were bought at the end of October, which is the point in time when the cooperation period started. The harvest of large fish took place in December 2006 (information gathered after completion of the study period); see Figure 33.

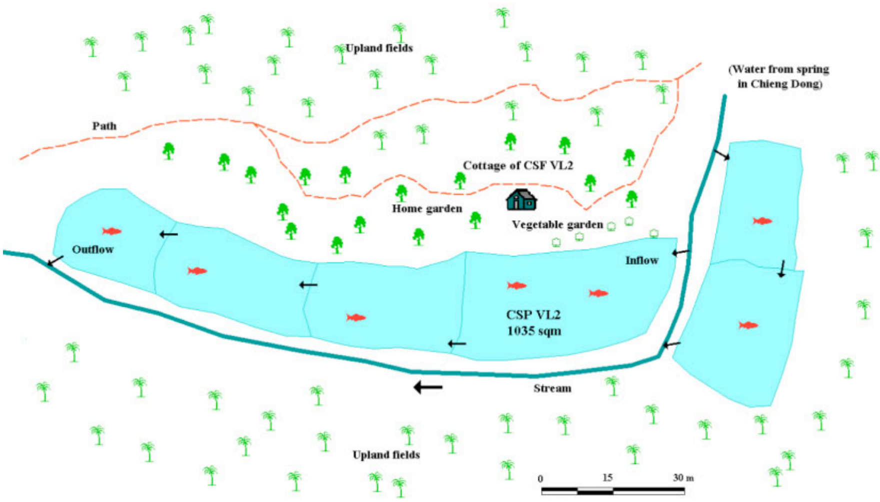


Figure 32: Sketch of case study pond (CSP) VL2

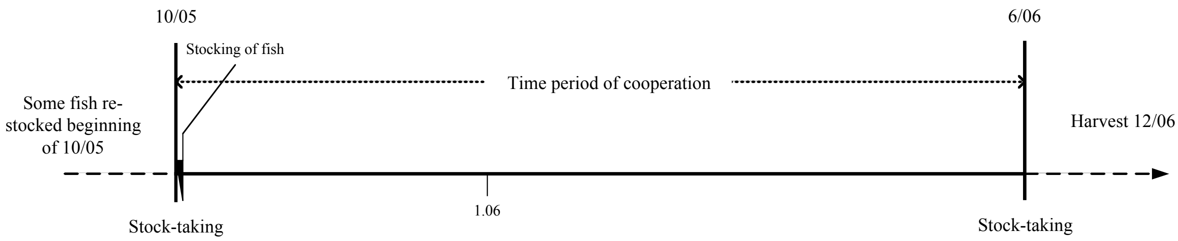


Figure 33: Fish stocking and harvest of VL2 during the cooperation period

6.1.7 The three case study farms that are not considered on the micro level

The farms CK3, SV3 and VL3 are not presented in the following text. In the case of CK3, there were discrepancies between stocked fish caused by unlisted fish transfers between ponds as well as incomplete recordings in the farmer's book. In the case of this farm, the cooperating farmer was the household head's wife. There appeared to be an unclear separation of responsibilities between the couple, which led to further confusion on the part of the researchers. Also in the case of SV3, there were discrepancies in fish amounts caused by uncontrolled fish harvests during a funeral procedure and unlisted fish transfers between ponds that were carried out by household members other than the cooperating farmer. At the end of the cooperation with VL3, after the fish were caught, it became obvious that many fish were missing. It is likely that fish were stolen and some might have been lost during a heavy flood in April 2006. General information about these farms and ponds can be observed in Tables 20-22. Sketches of the three case study ponds can also be viewed in the appendix.

Table 20: Selected features of the case study farms in Chieng Khoi commune during the cooperation period

	CK1	CK2	CK3
Total HH members (children)	5 (3)	6 (2)	6 (1)
Cooperating farmer: function in household/village (year of birth)	Head of household/head of the farmers' union (1962)	Father of household head (1945)	Wife of HH head (HH head was working at the extension office YC)
Total farm size	~ 1.5 ha	~ 2 ha	> 1 ha
Crop production and area	Paddy rice (~ 1 600 m^2); maize and cassava (~ 8 000 m^2); home gardens (~ 2 500 m^2, e.g. mango, litchi, pineapple, banana); additional area rented for maize production; management of forest land (~ 4 000 m^2)	Paddy rice (~ 1 650 m^2); maize and cassava (~ 1 ha); home gardens (~ 4 000 m^2, e.g. mangos, litchis, vegetables); 50-60 banana shrubs; management of forest land (~ 4 600 m^2)	Paddy rice (~ 2 000 m^2); cassava; maize; peanuts; mushrooms (under farmer's house)
Animal husbandry	4 heads of cattle, varying numbers of poultry	1 buffalo, 2 heads of cattle, varying number of poultry (± 10); later: 1 head of cattle and 2 goats in addition	2 heads of cattle, varying number of pigs (~ 5), goats (~ 5) and poultry (~ 35)
Farm income: total and from fish sales (in 2004)	> 10 mil VND (> 630 US$); no fish sales	~ 11 mil VND (~ 690 US$); no fish sales	Important income source: off-farm job at YC extension service
Short description CSP: size[1], depth[1], location, other features	533 m^2; depth: 1.08 m; located next to farmer's house; surrounded by trees	1 347 m^2; depth: 1.36 m; next to farmer's house; surrounded by trees	455 m^2; depth: 1.40; next to farmer's house; mostly no water flow; Napier grass grown on pond dykes
Building of CSP (purpose)	1986 (fish production)	1990, deepened in 1998 (fish production)	~ 1995 (fish production)
Major rearing period[2]	April 03 until September 05 (~ 29 months)	July 04 until October 06 (~ 27 months)	January 05 until May 06 (~ 16 months)
Fish species reared in CSP and their sources	GC, MRI, CC, BHC, SB and TIL; partly purchased from SL hatchery	GC, MC, MRI, CC, SC, BHC, TIL; from own nursery pond and purchased from other farmers	GC, MC, MRI, SC, BHC, CC, TIL, PI; purchased from local hatchery and lowlands, nursed on the farm
Major feed inputs in CSP during cooperation period[3]	Cassava leaves, banana leaves, grass/weeds and aquatic plants, buffalo manure collected from roads or neighbouring animals	Leaves and chopped stems from banana, grass/weeds, aquatic plants, buffalo manure	Manure from cattle and pigs, grass/weeds, rice bran, Napier grass, banana and cassava leaves
Special feeding practices	Use of a feeding ring	Use of a feeding ring and bamboo mat on the pond bottom (for feeding rice bran)	No use of a feeding ring
Occurrence of GC mortalities	Yes, in August/September 05	Yes, in November 04 and September 05	Yes, in June/July 05
Labour input for CSP[3]	60 min day^{-1}	111 min day^{-1}	60 min day^{-1}
Short description of other ponds	One more pond in upland field area, supplied by precipitation and spring, used only seasonally, pond cannot be dried out	One more pond (~ 135 m^2) for nursing fish, next to farmer's house, later used during cooperation period as a paddy field	One more pond located next to CSP, stream between ponds, partly cemented, water supplied by CSP

For abbreviations and legend see Table 22

Table 21: Selected features of the case study farms in Sap Vat commune during the cooperation period

	SV1	SV2	SV3
Total HH members (children)	5 (2)	5 (1)	7, later 6 (2)
Cooperating farmer: function in household/village (year of birth)	Household head/headman, later: head of the farmers' union (1962)	Head of household (1980)	Father of household head/head of the union of elderly people (1944)
Total farm size	~ 1.9 ha	~ 1.5 ha	> 2 ha
Crop production and area	Paddy rice (~ 5 000 m^2), high proportion of (glutinous) rice is sold; maize, cassava, banana and cotton (> 1 ha); management of forest land (~ 5 000 m^2)	Mango (~ 5 000 m^2); paddy rice (~ 2 000 m^2); maize, cassava (~ 4 000 m^2) and vegetables	Paddy rice (~ 2 500 m^2); maize and cotton (~ 6 000 m^2); fruits and vegetables (~ 8 000 m^2)
Animal husbandry	4 buffalos (later: 1 buffalo sold), varying number of poultry (~ 30-40)	3, later 4 buffalos, varying number of poultry (up to 100 chicken and ducks); later: 2 goats in addition	3 buffalos, ~ 60 chicken; 1 "Ban" pig
Farm income: total and from fish sales (in 2004)	~ 25 mil VND (~ 1 575 US$), including off-farm salary of wife, ~ 6 mil VND from fish production	~ 20 mil VND (~ 1 260 US$); mostly from mango sales and ~ 5 mil VND from fish sales	~ 20 mil VND (~ 1 260 US$), of which ~ 3-4 mil VND from fish sales
Short description CSP: size[1], depth[1], location, other features	580 m^2; depth: 1.08 m; next to farmer's house; small part of pond concreted, surrounded by trees, e.g. fig and mango	1 028 m^2; depth: 1.11 m; located near other ponds in paddy field area; vegetable production on embankment, pond surrounded by trees, e.g. bamboo	340 m^2; depth: 1.04 m; near farmer's house; vegetable production on pond embankment, surrounded by trees, e.g. tamarind
Building of CSP (purpose)	1976, deepened and broadened in 1997 (fish production)	1980 (fish production)	In the 1960s (fish production)
Major rearing period[2]	July 04 until October/November 05 (~ 16.5 months)	July 04 until October 05 (~ 14 months)	August 04 until February 06 (~ 18 months)
Fish species reared in CSP and their sources	GC, MRI, CC, SB, CAF (partly killed during winter), TIL from different sources (e.g. other villagers), later: SC, BHC	GC, MC, MRI, SC, BHC, CC, TIL, from own nursery pond (originally from YC hatchery) and other farmers	GC, CC, MC, MRI, SB, PI and TIL from own nursery pond (originally from lowlands)
Major feed inputs in CSP during cooperation period[3]	Banana leaves, grass/weeds, aquatic plants, figs	Grass/weeds, aquatic plants, buffalo manure	Banana leaves, buffalo manure, grass/weeds
Special feeding practices	Use of a feeding ring	No use of a feeding ring	No use of a feeding ring
Occurrence of GC mortalities	Yes, in August/September 04	Yes, in September/October 05	Not during cooperation period, but shortly after completion
Labour input for CSP[3]	77 min day^{-1}	85 min day^{-1}	38 min day^{-1}
Short description of other ponds	One more pond (850 m^2) in paddy field area, used for nursery and grow-out, cannot be dried out due to water source on pond bottom	2 more ponds; nursery pond next to farmer's house; grow-out pond in upland field area, only seasonally used, area occasionally used for rice culture	3 more ponds with a total area of ~ 2 600 m^2; all located near farmer's house, ponds temporarily used for vegetables or paddy rice production

For abbreviations and legend see Table 22

Table 22: Selected features of the case study farms in Vieng Lan commune during the cooperation period

	VL1	**VL2**	**VL3**
Total HH members (children)	5, later 3 (1)	4 (2)	5 (1)
Cooperating farmer: function in household/village (year of birth)	Head of household/vice head of village (1967)	Head of household (1962)	Father of household head/head of the union of elderly people and war invalids (1944)
Total farm size	~ 1.4 ha	~ 2.4 ha	~ 1.8 ha
Crop production and area	Paddy fields (~ 2 700 m^2); maize, cassava (~ 7 000 m^2) and fruits; management of forest area (~ 2 000 m^2)	Paddy area (~ 750 m^2, not completely used for rice production); maize and cassava (~ 1.3 ha); 100 m^2 home gardens; management of forest land	Rice (1 300 m^2); maize, cassava and peanuts (> 1 ha); fruits and vegetables; management of forest land
Animal husbandry	3 buffalos, 2 goats, varying number of poultry (~ 12 animals)	1 buffalo, 2 heads of cattle, varying numbers of poultry (~ 30 animals) and goats (~ 5 animals), pigeons	2 buffalos, 2 goats, varying number of poultry (~ 20 animals)
Farm income: total and from fish sales (in 2004)	~ 8 mil VND (~ 504 US$), of which ~ 2 mil VND from fish sales	~ 18 mil VND (~ 1 134US$), of which ~ 5 mil VND from fish sales	~ 9 mil VND (~ 567 US$), of which ~ 3.4 mil VND from fish sales
Short description CSP: size[1], depth[1], location, other features	620 m^2; pond depth: 1.43 m; between upland fields, located next to other ponds; surrounded by trees	1 035 m^2; pond depth: 1.54 m; upland area; grow-out pond, vegetables grown on pond embankment, surrounded by trees	540 m^2; pond depth: 1.17 m; upland area; surrounded by trees
Building of CSP (purpose)	2000 (fish production)	1980 (fish production)	> 30 years ago (fish production)
Major rearing period[2]	April 04 until June 06 (~ 26 months)	October 05 until December 06 (~ 14 months)	June 05 (majority of fish lost, probably in April 06)
Fish species reared in CSP and their sources	GC, SC, MRI, TIL and SB from own nursery pond (originally from YC hatchery) and other farmers	GC, SC, MRI, CC from own nursery pond and purchased from other farmers	GC, MRI, CC, SC, TIL; fish partly bought from related farmers in another commune
Major feed inputs in CSP during cooperation period[3]	Leaves and chopped stems of banana, aquatic plants	Leaves and chopped stems of banana, aquatic plants	Cassava and banana leaves, aquatic plants and buffalo manure
Special feeding practices	Use of a feeding ring	Use of a feeding ring	Use of a feeding ring
Occurrence of GC mortalities	Not during cooperation period	Not during cooperation period	Yes, in July/August 2005
Labour input for CSP[3]	58 min day^{-1}	77 min day^{-1}	69 min day^{-1}
Short description of other ponds	Two more ponds, both located in upland field areas (grow-out, nursery)	Two more ponds, both located in paddy field areas	Two more ponds; one built during cooperation period (upland field area)

BHC = Bighead carp; CAF = Catfish; CC = Common carp; CSP = Case Study Pond; GC = Grass carp; HH = Household; MC = Mud carp; MRI = Mrigal; PI = Pirapitinga; SB = Silver barb; SC = Silver carp; SL = Son La; TIL = Tilapia; VND = Vietnamese Dong; YC = Yen Chau

[1]This data was measured; water depth is the average of different measurements over the cooperation period at a defined site

[2]Rearing period from the major stocking until the major harvesting procedures; period differs from the cooperation period

[3]Data derived from farmers' record books; major feed inputs on fresh matter basis

6.2 **Limnological conditions**

6.2.1 Dissolved oxygen, water temperatures, pH, transparency, colour and redox-potentials in the ponds

Table 23 shows the averages as well as the minimum and maximum values of dissolved oxygen (DO) contents, temperatures, pH as well as the Secchi disk depths (SDD) of the case study ponds, which were measured monthly in the morning and afternoon. Fluctuations of these parameters over a year in the case of two ponds are illustrated in Figure 34. Generally, with higher water temperatures, morning DO levels as well as the SDD depths decreased. Despite the tendency of similar movements of DO and SDD, there was no strong correlation among those parameters.

Frequently, low DO levels were observed at dawn, which resulted in fish gulping at the pond surface. During the considered period, the lowest DO concentration measured was 0.4 mg l^{-1}; whereas the average DO levels at 8 a.m. ranged between 2.2 and 3.9 mg l^{-1}. The highest amplitude of DO between morning and afternoon measurements was found in pond SV1. Diurnal fluctuations in DO, temperature and pH of this pond as well as of pond CK1 are shown in Figure 35. In the example of SV1, the DO concentration was close to zero in the early morning hours.

During the monthly measurements, the lowest water temperatures were observed in January 2005 with morning temperatures ranging between 13.4 and 13.7°C in the case study ponds in Chieng Khoi and between 14.1 and 14.6°C in the ponds of Sap Vat, respectively. The low water temperatures in the wintertime caused mortalities of tilapia in four of the six ponds. From April 2005 until May 2006, the measured water temperatures ranged from 15.2 to 33.2°C.

DO and temperature measured at different pond depths in pond SV2 in the morning and afternoon are illustrated in Figure 36. In the respective pond, average differences in DO between the surface and bottom layer were higher in the afternoon (1.3 mg l^{-1}) compared with the morning (0.7 mg l^{-1}). The same was also found in the case of temperatures with average differences from 0.3°C at 8 a.m. and 1.2°C at 4 p.m.

The pH of the ponds usually ranged between 7 and 8 (see Table 23), the pH near the bottom was usually lower compared with the pH of upper water levels. The redox potential (E_H) of the water ranged between 315 and 461 mV in the two case study ponds demonstrated in Figure 37.

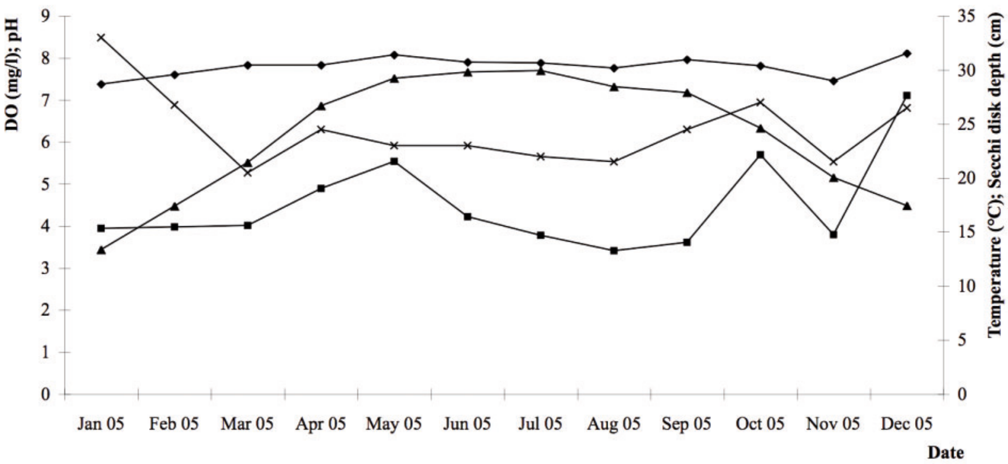
While during the dry season, pond colour usually varies between green and grey, during the rainy season, water turns into a rather red-brownish or "milk-coffee" colour. There were, however, differences among the ponds. Thus, pond SV1 was mainly greenish-greyish coloured, while the predominant colour of pond CK1 was "milk-coffee-like" during most of the year. Observations showed that turbid and reddish waters frequently derived from heavy rain and sediments that entered with the water inflow. This was also caused by the bathing of buffalos or humans in the ponds as well as fish catching activities.

Table 23: Dissolved oxygen contents, water temperature, pH, Secchi disk depths and water colours in the case study ponds

CSP	No[1]	Time	DO[2] (mg l^{-1})	T[2] (°C)	pH[2]	SDD (cm)	Water colour (tendencies)
CK1	12	8 a.m.	3.5±1.7	21.9±5.0	7.6±0.3	30.8±12.8	Dry winter season:
			Min: 1.0	Min: 15.8	Min: 7.1	Min: 9*	greyish
			Max: 5.8	Max: 29.1	Max: 8.0	Max: 51	Wet summer season:
		4 p.m.	5.3±1.9	23.5±5.3	7.6±0.2	35.5±16.9	red-brownish, turbid
			Min: 0.4*	Min: 17.3	Min: 7.2	Min: 5*	
			Max: 7.5	Max: 31.6	Max: 8.0	Max: 61	
CK2	12	8 a.m.	3.7±1.2	22.5±4.9	7.8±0.3	20.9±6.1	Dry winter season:
			Min: 2.2	Min: 16.1	Min: 7.2	Min: 3*	grey-greenish
			Max: 5.8	Max: 29.2	Max: 8.2	Max: 30	Wet summer season:
		4 p.m.	5.7±2.1	24.6±4.7	7.9±0.3	25.4±8.5	brown-greenish, turbid
			Min: 1.5*	Min: 18.4	Min: 7.2	Min: 2*	
			Max: 9.7	Max: 30.9	Max: 8.2	Max: 36	
SV1	12	8 a.m.	3.0±2.0	23.9±4.8	7.6±0.2	32.5±11.2	Grey-greenish colour
			Min: 1.0	Min: 15.2	Min: 7.2	Min: 20	most time per year,
			Max: 6.7	Max: 29.3	Max: 7.9	Max: 67	partly brownish in
		4 p.m.	6.6±2.2	26.2±6.0	7.8±0.3	33.9±12.2	summer time
			Min: 2.3	Min: 15.2	Min: 7.5	Min: 23	
			Max: 11.6	Max: 33.2	Max: 8.3	Max: 68	
SV2	12	8 a.m.	3.9±1.4	24.4±4.6	7.8±0.2	33.3±6.0	Grey-greenish colour
			Min: 1.8	Min: 15.9	Min: 7.5	Min: 23	most time per year,
			Max: 6.0	Max: 30.2	Max: 8.1	Max: 41	partly brownish in
		4 p.m.	5.8±1.5	26.4±5.2	8.0±0.2	36.3±6.7	summer time
			Min: 3.9	Min: 16.2	Min: 7.6	Min: 23	
			Max: 9.2	Max: 32.6	Max: 8.3	Max: 43	
VL1	9	8 a.m.	2.2±0.6	22.9±3.3	7.4±0.1	56.7±8.3	Dry winter season:
			Min: 1.0	Min: 18.5	Min: 7.2	Min: 40	grey-greenish
			Max: 3.1	Max: 27.6	Max: 7.5	Max: 68	Wet summer season:
		4 p.m.	3.9±1.1	23.6±3.6	7.4±0.2	59.9±12.1	brown-greenish, turbid
			Min: 2.9	Min: 18.3	Min: 7.2	Min: 40	
			Max: 6.5	Max: 28.4	Max: 7.9	Max: 73	
VL2	6	8 a.m.	3.4±0.8	21.5±3.1	7.5±0.3	49.7±14.0	Mostly colour like a
			Min: 1.9	Min: 17.9	Min: 7.0	Min: 31	milk-coffee
			Max: 4.6	Max: 23.9	Max: 7.8	Max: 67	
		4 p.m.	4.5±0.6	22.5±3.7	7.6±0.4	52.2±11.5	
			Min: 3.8	Min: 18.6	Min: 7.0	Min: 34	
			Max: 5.7	Max: 29.3	Max: 7.9	Max: 66	

CSP = Case study pond; DO = Dissolved oxygen; T = Water temperature; SDD = Secchi disk depth
[1]Number of consecutive monthly measurements used for calculation (April 2005 to May 2006); [2]Measured from the platform inside the pond at three different pond depths, values used for calculation of the values presented in this table are the averages between the three depths; *Measured after a hailstorm in April 2006

a)



b)

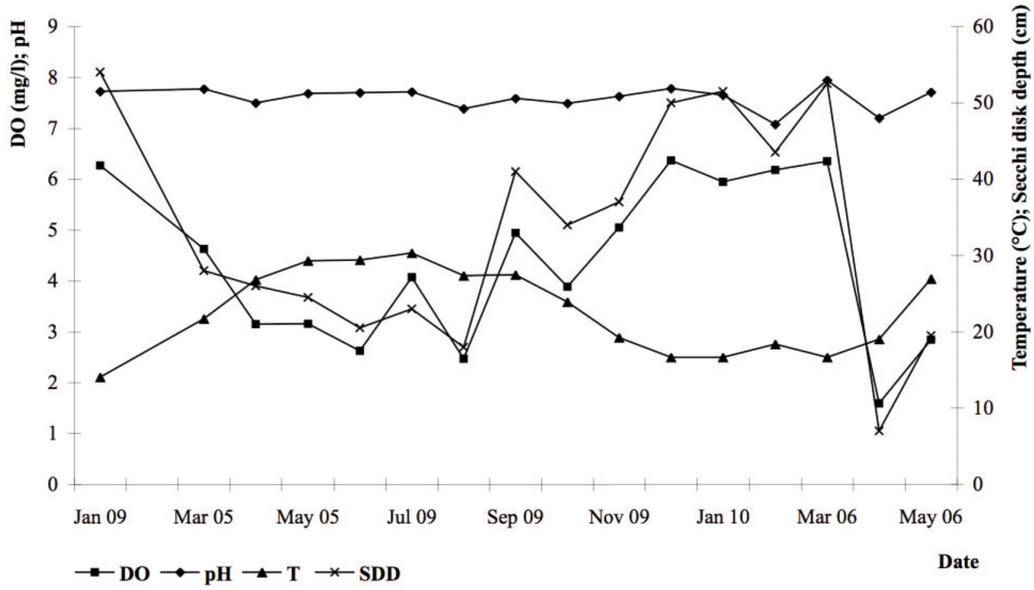
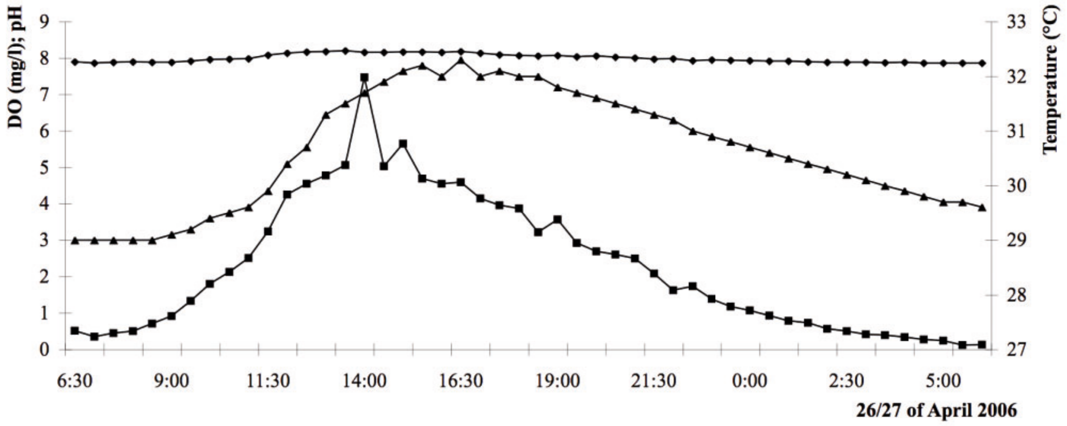


Figure 34: Fluctuation of dissolved oxygen (DO), temperature (T), pH and Secchi disk depths (SDD) (a) in pond CK2 over one year and (b) in pond CK1 over 17 months
(Values are means of measurements of morning and afternoon sampling)

a)



b)

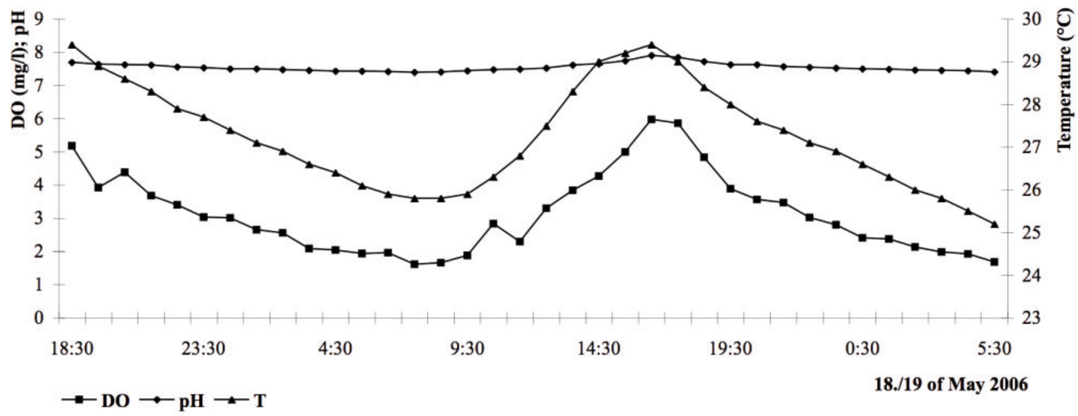


Figure 35: Diurnal fluctuation of dissolved oxygen (DO), temperature (T) and pH measured over 24 hours in pond SV1 (a) and 36 hours in pond CK1 (b)
(Measured in the mid of the water column)

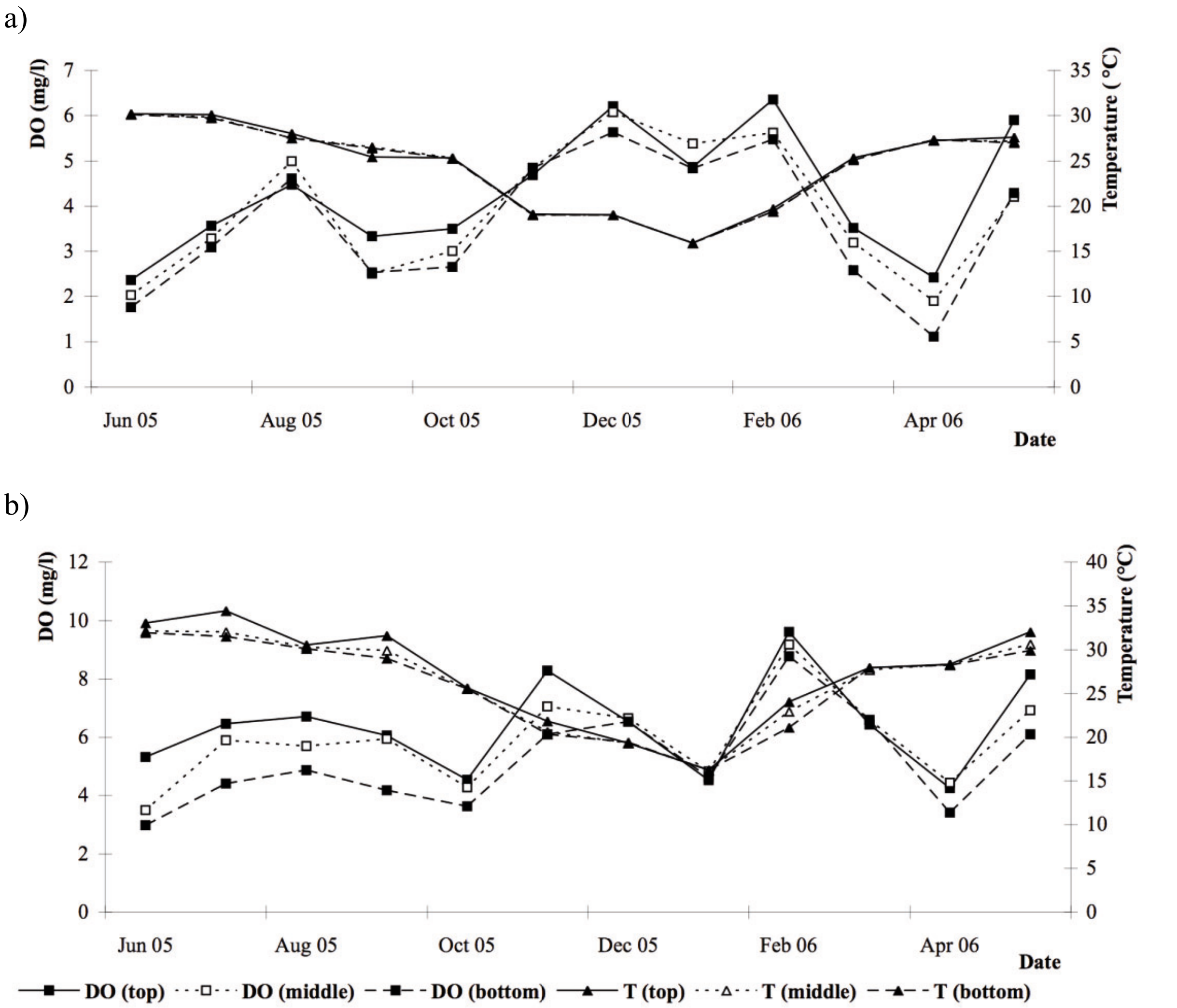


Figure 36: Content of dissolved oxygen (DO) and water temperature (T) measured at different pond depths in pond SV2 (a) at 8 a.m. and (b) at 4 p.m.

a)

b)

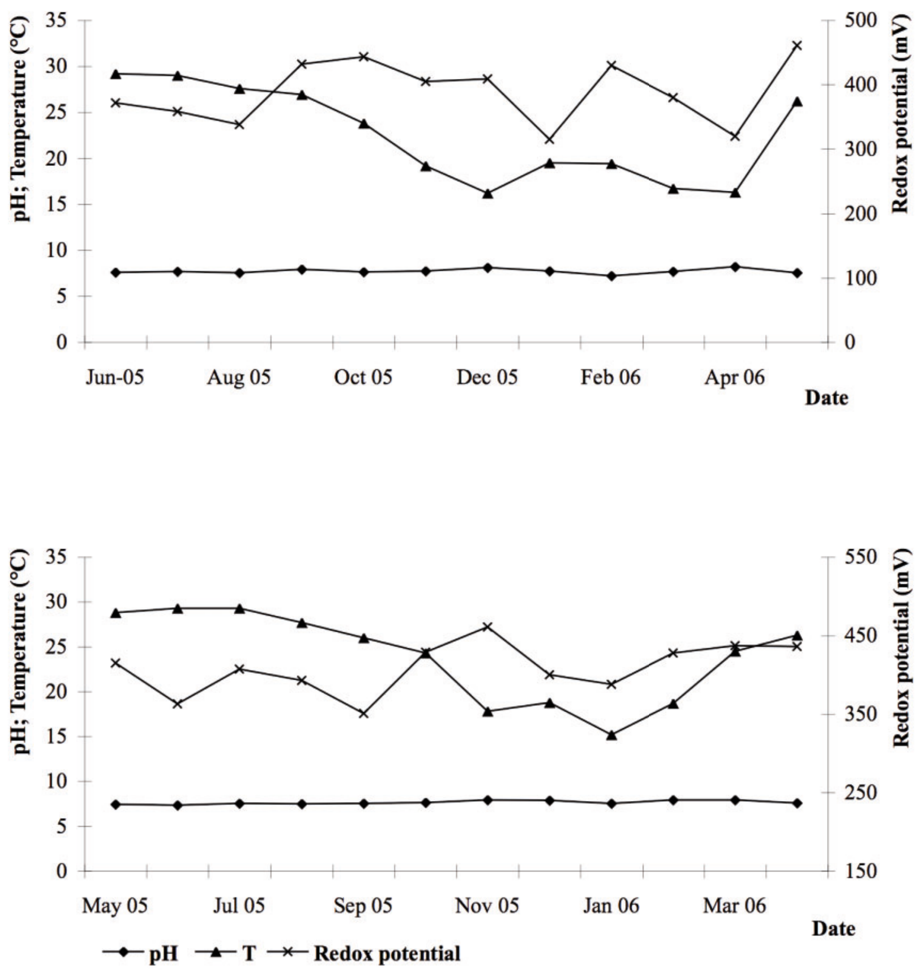


Figure 37: pH, temperature and redox potential (E_H) over a year in pond (a) CK2 and (b) SV1
(Values from all parameters refer to the mid water depth, measured at 8 a.m.)

6.2.2 The water flow and its use as a source for dissolved oxygen

All the ponds had, at least theoretically, access to flowing water either directly from canals, streams or from upstream ponds. However, the amounts of water differed enormously between days and even among hours. Frequently it occurred that there was water flowing in the morning but not in the afternoon or vice versa.

Table 24 shows the theoretical time required for exchanging the pond water only through the water flow using the example of four case study ponds. In pond VL2 with a continuous water supply from a year-round water-carrying stream nearby, a relatively high amount of water flowed regularly into the pond. Here, the turnover rate was only 8 days, while 13 to 32 days were required to completely exchange the pond water of the other ponds. Taking into account only the highest water-flow measured in ponds SV1 and SV2, roughly one-third of the pond water could be exchanged in one day. However, this high water flow usually was associated with heavy rainfall during the rainy season and was the exception rather that the norm. The fluctuations in the water flow amounts over a year are demonstrated in Figure 38. The water flow fluctuated among the monthly samplings; in certain months, there was no flow at all.

Due to the high variations in the amounts of water flow that were determined once per month, the above-mentioned data gives only a rough idea about typical ranges of the water flow. For calculating the total water that flows through the ponds, measurements that were more continuous would be required.

Table 24: Average water flow and water turnover rate determined in four ponds

Pond	Pond volume[1] (m^3)	Water inflow[2] (months)	Average water flow[3] ($l\ min^{-1}$)	Water turnover rate[4] (days)
CK1	576	9 (12)	12.6±12.7	32
SV1	626	8 (12)	34.5±47.1	13
SV2	1 141	6 (12)	52.1±94.7	15
VL2	1 594	6 (6)	145.4±227.6	8

[1]Average pond depth x pond size (data sourced from Tables 20-22); [2]Months with water flow of total consecutive monthly measurements used for this calculation (from May 05 until April 06, in the case of pond VL2: from November 05 until April 06); [3]Value considers also those months without water inflow; underlying data are averages between morning and afternoon measurements; [4] Turnover rate calculated on the basis of the average water flow amounts

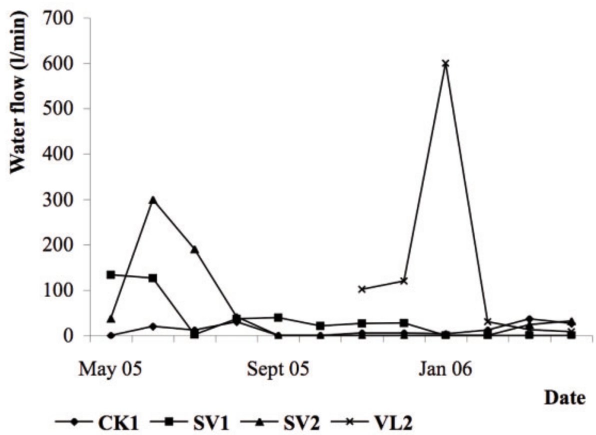


Figure 38: The monthly measured amounts of water* ($l\ m^{-2}$) flowing through four case study ponds
*as averages between the morning and afternoon measurements

A source of DO is the inflowing water. Especially in the morning, the DO concentrations in the inflowing water are regularly higher compared to the DO concentration in the pond water. In Figure 39 the DO levels and water temperatures in the pond as well as in the inflowing water is illustrated using the example of pond CK1. However, the DO-carrying water that enters the ponds often does not prevent fish from gulping at the surface, which indicates DO insufficiencies. Fish are actually under more pressure in times of very turbid water and sudden end of water flow.

In order to assess the potential impacts of the inflowing DO on the pond DO, a simple calculation has been set up in Table 25. The examples selected in this table represent individual morning measurements with amounts of water flow that are near the averages of water flow measured over a year in the respective ponds. In those examples, over half (53%) of the inflowing DO is accumulated in the pond on average, while the remaining DO is let out of the system via the outflow. Extrapolating the DO amounts accumulated over a day, the pond water has been enriched with 0.1 to 0.2 mg l^{-1} DO per litre. However, this calculation is simplified and neglects, for example, all DO producing and consuming effects in the pond. Furthermore, the difference among the DO in the inflow as compared to the DO in the outflow is usually higher in the morning as compared to the afternoon. Thus, the impact of DO from the water-flow is probably over-evaluated in this calculation.

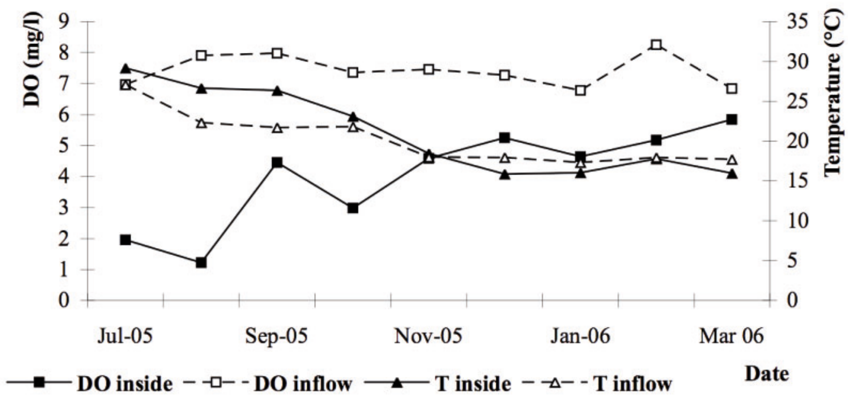


Figure 39: Levels of dissolved oxygen (DO) and temperature (T) inside the pond and in the inflowing water measured at 8 a.m. in pond CK1
(Values measured inside the pond are averages of measurements in three water depths)

Table 25: The entry of dissolved oxygen (DO) with the water flow

Pond	Date	Pond depth (m)	DO inside pond[1] (mg l^{-1})	Water flow (l min^{-1})	DO inflow (mg l^{-1})	DO outflow (mg l^{-1})	Entry of DO to the pond water[2] (g day^{-1})	Entry of DO to the pond water[3] (mg l^{-1} day^{-1})
CK1	20.08.05	1.1	1.2	12	7.9	1.1	118	0.2
SV1	23.08.05	1.19	1.1	36	3.3	1.5	93	0.1
SV2	16.09.05	0.94	2.8	30	5.5	3.2	99	0.1
VL2	23.11.05	1.56	3.5	107	5.8	4.1	262	0.2

[1]Averages of measurements at three water depths; measured at 8 a.m.
[2]((DO inflow – DO outflow) x Water flow x 60 x 24) / 1000
[3](DO inflow – DO outflow) x Water flow x 60 x 24 / Pond depth x pond size x 1000 (for pond sizes (m^2) see Tables 20-22)

The pond depths varied over the cooperating period; see Figure 40. In this figure, pond SV3 is also presented (although not further analysed on the micro level). Here, due to a lack of water supply, water level dropped to 55 cm during the dry season. High variations were also observed in pond CK2 with a difference of 57 cm between the highest and lowest water levels.

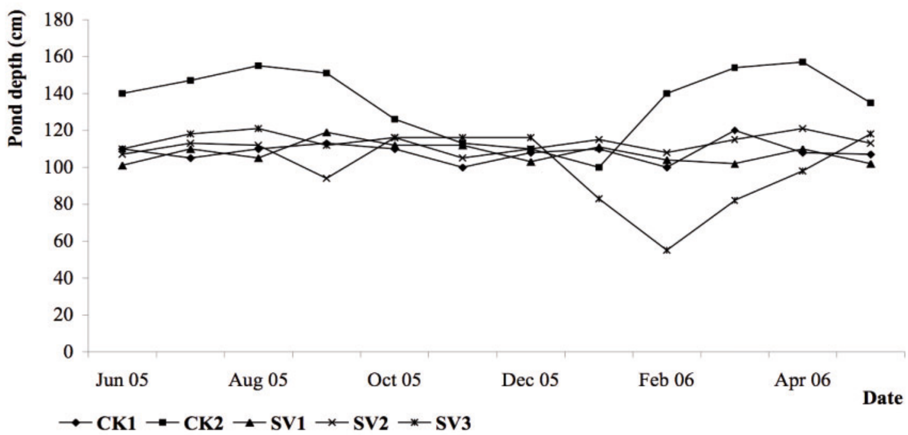


Figure 40: Variation of water depths in different ponds over a one-year period

6.2.3 Depth, pH and redox potential of the pond mud

While the pH of the water column usually ranged between 7 and 8 in all ponds, the pH was usually lower than 7 in the pond mud. The average mud redox potential (E_H) was between 24 and 50 mV in the presented ponds (Table 26).

Table 26: Average pond depths, pH and redox potential (E_H) of the pond mud

Pond	No[1]	Mud depth (cm)	pH[2]	Redox[2] (mV)
CK1	12	15	7.0±0.5	50±25
CK2	12	13	6.8±0.3	34±43
SV1	12	14	6.7±0.1	31±32
SV2	12	16	6.8±0.3	36±36

[1]No = Number of consecutive monthly measurements used for calculation; [2]Measured at 8 a.m.

6.2.4 Abundance of phyto- and zooplankton

Table 27 shows the plankton biomasses as well as the number of phyto- and zooplankton individuals caught from the case study ponds. The average dried plankton masses ranged from roughly 0.5 to 1.5 mg l^{-1}. The plankton biomasses extracted from the ponds over the course of several months are presented in Figure 41. While there were similar trends concerning the plankton biomasses among the ponds, there was no clear difference between the plankton abundance between summer and winter.

The lowest plankton biomass has been observed in pond VL2, which is also the pond with the highest and most regular water flow. In Figure 42, the availability of plankton biomass is compared with the amount of water flow in the respective pond. Here it is shown that there appears to be a tendency of lower plankton abundance with higher water flows.

The number of phytoplankton individuals found in a litre of water ranged from roughly 15 000 (VL2) to 78 000 (SV1), the number of individual zooplankton from 86 (VL1) to 267 (SV1) individuals. The highest number of individuals of both phyto- and zooplankton have been caught from pond SV1.

The phytoplankton individuals were characterized into divisions and classes (Table 27). The majority of the captured phytoplankton belongs to the classes of green algae (Chlorophyceae), euglenoids (Euglenophyceae) and dinoflagelattes (Dinophyceae). While the presence of green algae was dominant in most ponds, the high abundance of euglenoids in CK2 as well as the abundance of dinoflagelattes in VL1 became obvious. Quantitatively, the most important genera of the green algae identified comprise *Scenedesmus*, *Pediastrum*, *Crucigenia* and *Chlorella*. The genera of euglenoids in pond CK2 comprise mainly *Euglena* (37%) and *Trachelomonas* (27%). In VL1, 93% of dinoflagelattes caught belong to the genus *Peridinium*. A detailed list with genera of phytoplankton identified as well as the distribution of the classes among the monthly samples in three case study ponds can be found in the appendix.

In general, blue-green algae (Cyanophyta) were not dominant in any of the ponds. Only in one case (pond CK1, May 06), the community of blue-green algae accounted for over half (57%) of the total phytoplankton classes available. The typical genera of the observed blue-green algae were *Microcystis* and *Phormidium*.

The zooplankton community was dominated by rotifers and larval stages of crustaceans (nauplius); see Table 27. The quantitatively most important genus of the rotifers was *Brachionus*; for a detailed list regarding the genera of identified zooplankton, see appendix.

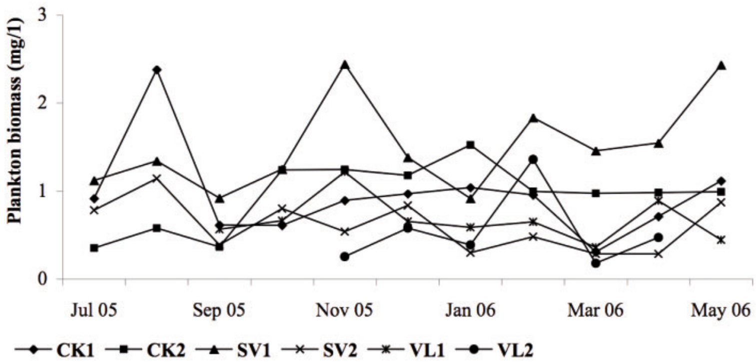


Figure 41: Availability of plankton biomass (dry matter) over several months

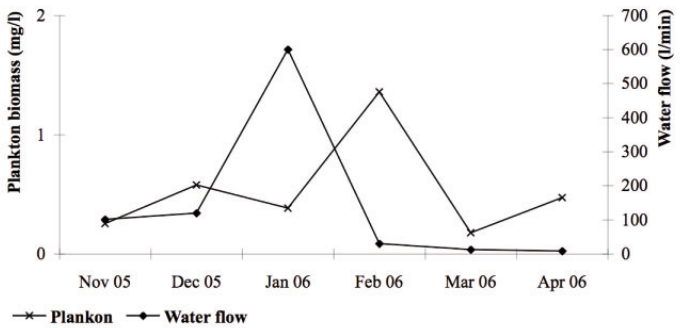


Figure 42: The availability of plankton biomass (dry matter) and the water flow in pond VL2 from November 05 until April 06
(Water flow and plankton determined in the morning (8-9.30) on the same day)

Table 27: Availability of plankton biomass in the case study ponds (July 05 until May 06)

	CK1	CK2	SV1	SV2	VL1	VL2
Period (no of samples)	07/05-05/06 (9)	07/05-05/06 (10)	07/05-05/06 (11)	07/05-05/06 (11)	09/05–04/06 (9)	11/05-04/06 (6)
Plankton biomass (mg DM l^{-1})	0.980 ± 0.583	0.943±0.393	1.511 ± 0.530	0.609 ± 0.292	0.669 ± 0.253	0.537 ± 0.427
Phytoplankton counts (total, Ind l^{-1})	**40 600 ± 24 331**	**64 200 ± 32 042**	**77 564 ± 38 373**	**39 964 ± 19 741**	**57 600 ± 44 626**	**14 867 ± 8 695**
Division: Heterokontophyta						
Chloromonadophyceae (Ind l^{-1})	2 044 ± 3 083	5 300 ± 11 058	7 273 ± 12 340	2 109 ± 3 947	489 ± 867	1 533 ± 3 040
Xanthophyceae (Ind l^{-1})	22 ± 67	280 ± 755	691 ± 1 849	273 ± 653	67 ± 141	67 ± 163
Chrysophyceae (Ind l^{-1})	1 422 ± 2 927	2 200 ± 4 339	636 ± 1 670	73 ± 135	1 622 ± 3 958	2 667 ± 5 953
Bacillariophyceae (Ind l^{-1})	1 511 ± 1 825	1 140 ± 1 907	4 091 ± 4 691	545 ± 401	311 ± 348	400 ± 620
Division: Chlorophyta						
Chlorophyceae (Ind l^{-1})	13 756 ± 9 458	13 920 ± 10 640	23 491 ± 17 475	16 127 ± 8 042	10 533 ± 4 916	5 233 ± 4 672
Zygnematophyceae (Ind l^{-1})	2 111 ± 3 326	1 560 ± 1 225	2 964 ± 2 465	1 455 ± 976	1 133 ± 1 049	567 ± 1 106
Division: Cyanophyta						
Cyanophyceae: Coccooneae (Ind l^{-1})	2 133 ± 4 409	3 040 ± 4 370	5 782 ± 4 405	4 182 ± 6 459	2 200 ± 2 263	600 ± 1 103
Cyanophyceae: Hormogoneae (Ind l^{-1})	4 778 ± 6 113	2 440 ± 2 168	8 127 ± 7 609	4 745 ± 2 920	2 133 ± 3 130	400 ± 669
Division: Dinophyta						
Dinophyceae (Ind l^{-1})	5 156 ± 5 204	3 940 ± 3 218	1 855 ± 2 107	2 109 ± 2 073	34 267 ± 36 327	1 367 ± 742
Division: Euglenophyta						
Euglenophycea (Ind l^{-1})	7 644 ± 5 820	30 380 ± 17 885	22 655 ± 14 062	8 345 ± 8 298	4 844 ± 4 852	2 033 ± 933
Division: Rhodophyta						
Rhodophyceae: Florideophycidae (Ind l^{-1})	22 ± 67	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Zooplankton counts (total, Ind l^{-1})	**218 ± 273**	**166 ± 213**	**267 ± 275**	**97 ± 56**	**86 ± 56**	**91 ± 51**
Nauplius (Ind l^{-1})	89 ± 115	32 ± 25	72 ± 76	48 ± 41	59 ± 37	55 ± 29
Copepoda (Ind l^{-1})	40 ± 78	5 ± 4	39 ± 44	10 ± 8	7 ± 8	11 ± 16
Cladocera (Ind l^{-1})	14 ± 16	4 ± 5	19 ± 20	6 ± 6	0 ± 1	9 ± 15
Rotifera (Ind l^{-1})	75 ± 146	126 ± 208	136 ± 203	33 ± 54	21 ± 21	15 ± 22

Ind = Individuals

6.3 In- and outputs in terms of fish, feed and manure

6.3.1 Fish stocking densities

Table 28 presents the stocking densities in the case study ponds during the first month of cooperation. In two cases (CK1 and VL1), all of the fish in the pond were stocked already several months prior to this time. In the other cases, only some fish were already in the pond, and additional fish were stocked during the first month after starting the cooperation. Usually, several stocking procedures took place. Fish were obtained from different sources (one's own nursery ponds, other farmers, traders or hatcheries) and consisted of different sizes. In the case of farm SV1, for example, a portion of the grass carp the farmer stocked consisted of fish with a relatively high initial weight of 1 kg, which explains the high biomass (> 3 tons ha^{-1}) at the beginning of the fish rearing period. To some extent, farmers were not able to buy fish according to their management concepts. For example, farmers from CK2 planned to purchase additional fish but no fish were available in the local hatchery at that particular time.

The stocking densities at the start of the cooperation period were on average 1.0±0.58 fish m^{-2} (1.59±1.30 tons ha^{-1}), comprising 4-8 different fish species such as the cyprinids grass carp, mud carp, mrigal, bighead carp, silver carp, common carp, common silver barb and the cichlid tilapia. Only in one case did a farmer additionally stock some catfish.

Grass carp made up the most prevalent cultured fish species in the ponds, comprising 66.7% of the total biomass stocked and 46.8% of the total fish numbers on average without considering the highly variable amounts of the self-recruiting tilapia. It is difficult to assess the actual tilapia stock, since the fish are often very small and cannot be completely caught by the nets that are used. Since tilapia reproduce in the ponds, their number frequently changes. The second most important fish species stocked are mud carp and mrigal, which on average account for 17.5% of the total biomass and 37% of the total fish numbers (excluding tilapia).

It is worth mentioning that farm SV3, which is not described on the micro level, raised pirapitinga in addition to the typical species described above. The farmers purchased these fish from lowland traders and did so according to a television broadcast. The farmer kept these fish (3-4 cm in length) together with other fish species in the same nursery pond and complained about a very low survival rate of his fish stock. The farmer estimated a recovery rate of only 25% of his fish compared to the usual survival rate of 75% in his nursery ponds.

Table 28: Stocking densities and species composition in the first month of cooperation*

	CK1	CK2	SV1	SV2	VL1	VL2
No of fish without tilapia	379	985	789	880	251	183
(with tilapia)	(836)	(1019)	(1039)	(880)	(284)	(420)
Fish m^{-2} without tilapia	0.7	0.7	1.4	0.9	0.4	0.2
(with tilapia)	(1.6)	(0.8)	(1.8)	(0.9)	(0.5)	(0.4)
Total biomass (kg)	157.6	98.8	188.8	18.4	114.0	59.3
Total biomass (tons ha^{-2})	2.96	0.73	3.26	0.18	1.84	0.57
Proportion GC in % of total biomass	65.3	58.1	54.7	67.9	88.4	65.8
(% of total no[1])	(55.4)	(37.1)	(20.9)	(59.1)	(50.2)	(57.9)
Proportion MC/MRI[2] in % of total	20.6	29.6	18.6	14.1	6.3	15.5
biomass (% of total no[1])	(31.7)	(42.5)	(42.6)	(35.2)	(44.6)	(25.7)
Proportion SC/BHC[3] in % of total	1.7	3.5	0.0	17.9	3.3	0.7
biomass (% of total no[1])	(4.7)	(7.4)	(0.0)	(5.7)	(5.2)	(8.2)
Proportion CC in % of total biomass	4.6	7.2	10.6	0.0	0.0	2.0
(% of total no[1])	(6.9)	(13.0)	(10.1)	(0.0)	(0.0)	(8.2)
Proportion of other fish species (except tilapia) in % of total biomass (% of total no[1])	SB: 1.4 (1.3)		SB: 7.7 (25.3) CAF: 3.2 (1.0)			

BHC = Bighead carp; CAF = Catfish; CC = Common carp; GC = Grass carp; MC = Mud carp; MRI = Mrigal; no = number; SB = Silver barb; SC = Silver carp

*Refers to already stocked fish and fish stocked within the first month of cooperation, real figure might be slightly higher since some fish were probably not netted (e.g. mud carp entrenched themselves in the pond mud); [1]Tilapia are not considered; [2]Exact species stocked: CK1: MC; CK2: MC + MRI; SV1: MRI; SV2: MC + MRI; VL1: MRI; VL2: MRI; [3]Exact species stocked: CK1: BHC; CK2: SC + BHC; SV2: SC + BHC; VL1: SC; VL2: SC

6.3.2 Gross chemical composition of selected fish feeds and application of feed and manure

Table 29 shows the gross chemical composition of some typical feeds used in the study area; this data has been partly published by Dongmeza et al. (2009a). The native plants listed in the table tend to be lower in crude protein (CP) and lipid (ether extract, EE) and higher in neutral detergent fibre (NDF) compared to the analysed leaves from cultivated crops. Among the listed feeds, cassava and mulberry leaves show the highest CP, and the cassava leaves show the highest lipid and gross energy (GE) content. The lowest NDF content among the leaves was found in the case of mulberry.

Quantitatively, the most important feed inputs (on a dry matter (DM) basis) supplied to the ponds during the cooperation period were fresh leaves from cassava, banana and maize, weeds collected from paddy fields as well as buffalo manure. Table 30 shows the amounts of the applied plant- and animal-derived pond inputs in terms of dry matter and crude protein as well as gross energy. Crop leftovers (cassava petioles and banana veins), that were usually not consumed by fish, were removed by farmers and subsequently also subtracted from this calculation.

Table 29: Gross chemical composition of selected fish feeds

Crop	Parts analysed / specifications	DM	CP	EE	NDF	ADF	L	CA	GE
		% of FM	% of DM	% of DM	% of DM	% of DM	% of DM	% of DM	MJ kg^{-1}
By-products and leaves from cultivated crops									
Cassava	Leaves without petioles (long-term variety)	28.1	23.4	8.7	29.5	17.8	6.7	7.6	21.0
Cassava	Leaves without petioles (short-term variety)	28.1	25.9	7.9	27.9	17.6	7.4	6.8	21.0
Cassava	Peel (long-term variety)	38.0	4.0	0.6	23.4	18.6	12.1	6.9	17.1
Cassava	Tubers (long-term variety)	78.6	1.4	0.3	7.5	2.0	0.5	2.5	16.4
Banana	Leaves without leaf veins	20.5	16.1	5.4	49.9	28.8	6.1	7.9	19.5
Maize	Leaves	36.7	13.0	2.6	56.1	34.9	6.6	11.0	17.2
Maize	Meal	86.9	10.9	6.5	13.6	3.7	0.3	1.4	20.9
Rice	Bran[1] (dry)	89.0	7.7	6.5	53.1	40.3	17.2	13.0	18.1
Bamboo	Leaves with soft stems	47.0	16.0	3.5	61.5	39.3	14.3	13.8	17.7
Mulberry	Leaves with soft stems	29.6	25.3	3.0	22.5	15.4	3.9	10.8	17.4
Napier grass	Blades of grass	19.8	16.3	2.9	60.5	36.8	6.6	13.6	16.0
Sweet potato	Leaves and soft stems	15.7	17.4	2.9	37.4	24.6	4.5	10.8	17.5
Native plants									
Barnyard grass	Blades of grass, contains also flowers	19.2	14.1	2.5	59.3	38.7	6.3	9.9	17.6
Mixed weeds[2]	Mix of weeds	14.6	15.6	2.3	62.4	35.7	9.5	13.3	16.9

ADF = Acid detergent fibre; CA = Crude ash; CP = Crude protein (N x 6.25); DM = Dry matter; EE = Ether extract; FM = Fresh matter; GE = Gross energy; L = Lignin (determined by solubilization of cellulose with sulphuric acid); MJ = Mega joule; NDF = Neutral detergent fibre
Values are means of duplicate analysis (n ≥ 2)
[1]Rice bran of low quality, partly containing rice hulls; [2]Mix of monocotyles and dicotyles usually collected from paddy fields and dykes (e.g. *Alternathera sessili, Commelina nudiflora, Cyperus rotundus, Digitaria timorensis, Eclipta prostata, Kyllinga monocephala, Sagitaria sagitifolia, Sporobolus indicus, Urochloa reptans, Wedelia calendulacea*)

The daily feed application was 15.4±4.8 kg fresh matter (FM) in the ponds, corresponding to 196.1±69.9 kg FM or 37.1±15.6 kg DM per hectare. In terms of crude protein and gross energy, farmers applied an average of 5.1±2.5 kg CP and 652±288 MJ per hectare and day. The amounts applied in terms of dry matter, crude protein as well as the water temperatures of a pond in the course of a year are shown in Figure 43. The amounts applied were higher in times of warmer water temperatures. The type of feed applied in the same period of time in the same pond can be referred to in Figure 17.

According to one hectare per year (FM basis), an average of 57.4±22.7 tons of green forage material (grasses and leaves), 9.6±8.9 tons of animal-derived manure and 4.5±3.7 tons of other feed items (e.g. rice and maize by-products, cassava tubers and peels, figs) were applied to the ponds. This data is based on notes collected from the farmers' record books. Some notes are based on estimations; for example, these estimations include the amount of fig fruits at farm SV1 that had fallen from surrounding trees into the pond as well as the application of manure that was not always first weighed.

The collection and transportation of the partly bulky feedstuff was considered to be labour intensive. The farmers' usual labour requirement for the investigated ponds was 78±19 min day^{-1} (Tables 20-22). It should be kept in mind that farmers owned more than one pond per household; thus, farmers usually spent several hours doing pond-related activities per day.

One type of input farmers apply to their ponds is Siam weed (*Chromolaena odorata*), which farmers refer to as "green manure". Siam weed is usually not eaten by the fish directly after its application; instead, it can be eaten 2-3 days after soaking in the pond water. The fresh leaves from the Siam weed have a CP content of 17% of DM, the content decreased to 16.8% of DM after leaves were soaked for a three-day period.

Manure was sourced either from one's own animals, collected from neighbours or found along the roads and was usually applied fresh by simply throwing it into the pond. Table 31 shows the amounts of animal-derived manure applied to the case study ponds. On average, farmers applied 5.1±4.7 kg DM (26.3±24.3 kg FM) of manure per hectare per day. In the two upland ponds (VL1 and VL2), comparatively little manure was applied.

On average, 94% of the animal-derived manure was from buffalo. The buffalo manure analysed (n = 4) contained 19.2% DM (of FM, Table 30), which consisted of 8.5% CP, 2.6% EE, 64.5% NDF, 51.2% ADF and 25.2% crude ash (CA). The gross energy was 15.8 MJ kg^{-1}. As compared to buffalo manure, the crude protein content of cattle manure was higher (9.9% of DM) and of pig manure lower (6.9% of DM). The pig manure usually came from the local breed "Ban" and contained high amounts of litter from animal stables.

The application of manure seemed to depend on whether manure was already on hand rather than if a particular pattern was being followed. Usually, manure was applied in the case of high availability of manure or an excess of time. Animal droppings near the pond were typically collected and thrown in immediately. The farmer of CK1 reported that he adapted the manure loading rate based on the pond colour and the smell of the pond mud; based on these observations, he made a decision on whether additional manure was required.

It was frequently observed at the pond site that fish (particularly tilapia) fed directly on floating manure particles.

Table 30: Amounts in biomass (dry matter), crude protein and gross energy applied and removed in the form of feed and manure during the cooperation period

Biomass and CP/GE source[1]	DM	Amount applied/ removed in pond CK1			Amount applied/ removed in pond CK2			Amount applied/ removed in pond SV1		
	% of FM	kg DM	kg CP	MJ	kg DM	kg CP	MJ	kg DM	kg CP	MJ
Products from cultivated crops applied										
Cassava leaves incl. petioles[1]	26.0	908.7	181.3	18055	284.7	56.8	5656	21.2	4.2	420
Cassava peel	38.0	48.8	2.0	834	178.8	7.2	3057	20.1	0.8	344
Cassava tubers (air-dried)	78.6	16.5	0.2	271	0.0	0.0	0	14.5	0.2	238
Fermentation residues[2]	25.5	65.3	2.5	1077	7.9	0.3	131	5.1	0.2	84
Banana leaves incl. leaf veins	17.9	377.0	49.0	7046	350.7	45.6	6555	633.2	82.4	11835
Banana stems	6.6	2.9	0.1	45	184.4	4.8	2859	2.9	0.1	45
Maize leaves	36.7	291.8	37.9	5018	330.2	42.9	5679	205.2	26.7	3529
Maize meal	86.9	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0
Rice bran	89.0	48.5	3.7	878	164.6	12.7	2979	25.8	2.0	467
Broken rice	85.1	40.1	2.2	701	0.0	0.0	0	68.1	3.8	1191
Rice straw[3]	90.0	0.0	0.0	0	41.4	1.7	662	97.2	3.9	1555
Bamboo leaves	47.0	35.1	5.6	621	90.3	14.4	1598	0.0	0.0	0
Mulberry leaves	29.8	5.1	1.3	88	0.0	0.0	0	0.0	0.0	0
Napier grass	19.8	1.2	0.2	19	0.0	0.0	0	11.9	1.9	190
Sweet potato leaves	15.7	6.8	1.2	120	1.6	0.3	27	0.0	0.0	0
Water morning glory	7.9	0.0	0.0	0	1.3	0.2	23	0.0	0.0	0
Figs[4]	12.7	0.0	0.0	0	0.0	0.0	0	128.2	9.6	2422
Products from native plants applied										
Barnyard grass	19.2	132.0	18.6	2324	112.8	15.9	1985	200.6	28.3	3530
Weed mixtures[5]	14.6	88.5	13.8	1496	322.9	50.4	5457	165.4	25.8	2796
Lemna/Azolla mixture[6]	7.1	63.5	11.5	782	235.2	42.6	2894	214.4	38.8	2638
Floating watermoss	6.9	4.4	0.6	48	11.7	1.7	129	0.0	0.0	0
Siam weed	23.3	77.7	13.2	1530	9.1	1.5	179	0.0	0.0	0
Removal of crop leftovers (uneaten feed)										
Cassava petioles[7]	20.6	-205.5	-11.1	-3288	-64.4	-3.5	-1030	-4.8	-0.3	-77
Banana leaf veins[8]	12.7	-89.7	-2.8	-1444	-83.4	-2.6	-1343	-150.6	-4.7	-2425
Animal-derived inputs										
Buffalo manure	19.2	471.0	40.0	7441	562.2	47.8	8883	140.2	11.9	2215
Cattle manure	21.2	17.8	1.8	267	101.1	10.0	1517	0.0	0.0	0
Pig manure[9]	32.2	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0
Total pond^{-1}		**2407**	**373**	**43930**	**2843**	**351**	**47895**	**1799**	**236**	**30999**
Total pond day^{-1}		**3.3**	**0.5**	**60**	**4.2**	**0.5**	**71**	**2.6**	**0.3**	**46**
Total ha day^{-1}		**61.3**	**9.5**	**1118**	**31.3**	**3.9**	**528**	**45.5**	**6.0**	**785**

Table to be continued…

Table 30 (continued)

Biomass and CP/GE source[1]	DM	Amount applied/ removed in pond SV2			Amount applied/ removed in pond VL1			Amount applied/ removed in pond VL2		
	% of FM	kg DM	kg CP	MJ	kg DM	kg CP	MJ	kg DM	kg CP	MJ
Products from cultivated crops applied										
Cassava leaves incl. petioles[1]	26.0	113.7	22.7	2259	80.7	16.1	1604	84.9	16.9	1687
Cassava peel	38.0	48.6	1.9	832	13.3	0.5	227	31.9	1.3	546
Cassava tubers (air-dried)	78.6	47.2	0.7	773	0.0	0.0	0	0.0	0.0	0
Fermentation residues[2]	25.5	24.3	0.9	400	1.8	0.1	29	7.4	0.3	122
Banana leaves incl. leaf veins	17.9	89.3	11.6	1668	427.5	55.6	7991	109.1	14.2	2039
Banana stems	6.6	0.0	0.0	0	34.7	0.9	538	15.6	0.4	241
Maize leaves	36.7	47.7	6.2	821	61.7	8.0	1060	3.7	0.5	63
Maize meal	86.9	1.7	0.2	36	0.0	0.0	0	0.0	0.0	0
Rice bran	89.0	564.5	43.5	10218	1.8	0.1	32	7.6	0.6	137
Broken rice	85.1	125.1	7.0	2189	0.0	0.0	0	0.0	0.0	0
Rice straw[3]	90.0	207.0	8.3	3312	0.0	0.0	0	0.0	0.0	0
Bamboo leaves	47.0	0.0	0.0	0	2.8	0.5	50	0.0	0.0	0
Mulberry leaves	29.8	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0
Napier grass	19.8	7.5	1.2	120	0.0	0.0	0	0.0	0.0	0
Sweet potato leaves	15.7	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0
Water morning glory	7.9	40.3	7.0	722	0.0	0.0	0	0.0	0.0	0
Figs[4]	12.7	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0
Products from native plants applied										
Barnyard grass	19.2	331.6	46.8	5836	2.9	0.4	51	25.0	3.5	439
Weed mixtures[5]	14.6	235.8	36.8	3985	3.9	0.6	67	5.5	0.9	93
Lemna/Azolla mixture[6]	7.1	79.0	14.3	972	110.2	19.9	1355	62.4	11.3	768
Floating watermoss	6.9	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0
Siam weed	23.3	19.8	3.4	389	0.0	0.0	0	0.0	0.0	0
Removal of crop leftovers (uneaten feed)										
Cassava petioles[7]	20.6	-25.7	-1.4	-411	-18.3	-1.0	-292	-19.2	-1.0	-307
Banana leaf veins[8]	12.7	-21.2	-0.7	-342	-101.7	-3.2	-1637	-26.0	-0.8	-418
Animal-derived inputs										
Buffalo manure	19.2	402.8	34.2	6364	1.9	0.2	30	10.2	0.9	161
Cattle manure	21.2	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0
Pig manure[9]	32.2	69.4	4.8	1063	0.0	0.0	0	0.0	0.0	0
Total pond^{-1}		**2408**	**249**	**41208**	**623**	**99**	**11106**	**318**	**49**	**5571**
Total pond day^{-1}		**3.7**	**0.4**	**63**	**2.2**	**0.3**	**38**	**1.5**	**0.2**	**26**
Total ha day^{-1}		**35.6**	**3.7**	**609**	**34.8**	**5.5**	**620**	**14.2**	**2.2**	**249**

CP = Crude protein; CSP = Case study pond; DM = Dry matter; FM = Fresh matter; MJ = Mega Joule (Gross energy)

Values are means of duplicate analysis (n ≥ 2)

[1]Long-term and short-term variety according to proximate proportion of being applied by farmers (~ 2/3 long-term variety, ~ 1/3 short-term variety); [2]Leftovers from liquor preparation; [3]Not analysed, assessed with 90% DM of FM, 4% CP and 16% MJ kg^{-1} GE; [4]Amounts based partly on estimations by farmers since fruits fell off of trees around the ponds, analysed fruits also include small insects (pests); [5]Mix of monocotyles and dicotyles usually collected from paddy fields and dykes (e.g. *Alternathera sessili, Commelina nudiflora, Cyperus rotundus, Digitaria timorensis, Eclipta prostata, Kyllinga monocephala, Sagitaria sagitifolia, Sporobolus indicus, Urochloa reptans, Wedelia calendulacea*); [6]Aquatic plants applied are usually a mixture of *Lemna sp.* and *Azolla sp.* = ~ 75% : 25%; [7]Calculated proximate proportion of cassava leaves : petioles (both fresh matter) = 71.5% : 28.5%; leaves and petioles were analysed separately; [8]Calculated proportion of banana leaves : veins (both fresh matter) = 66.5% : 33.5%; leaves and veins were analysed separately; [9]Manure derived from "Ban" pigs reared by neighbours and contained also litter material

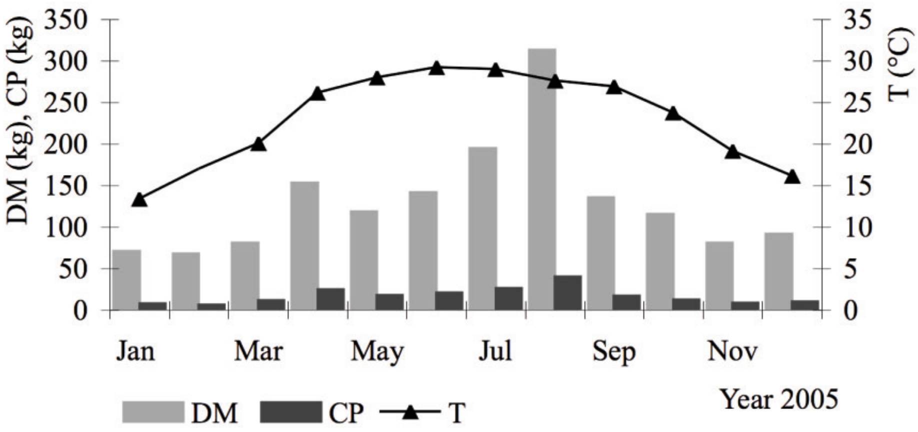


Figure 43: Monthly application of feed (in kg dry matter (DM) and kg crude protein (CP)) and water temperature (T) in the case study pond CK2

Table 31: Average daily animal-derived manure application in fresh and dry matter

	CK1	CK2	SV1	SV2	VL1	VL2
Fresh matter (kg ha^{-1} day^{-1})	64.6	37.5	18.5	34.2	0.6	2.4
Dry matter (kg ha^{-1} day^{-1})	12.4	7.3	3.5	7.0	0.1	0.5

6.3.3 Fish yields

The biomass of in- and outputs in terms of aquatic species as well as weight gain and food conversion ratio (FCR) in the ponds over the cooperation period are shown in Table 32. The net production of cultured fish and self-recruiting species was on average 1.54±0.33 tons ha^{-1} year^{-1} and ranged from approximately 1.1 to 1.9 tons ha^{-1} year^{-1}. The relatively low weight gain at farm SV2 can be partly attributed to the occurrence of theft, which was reflected in low fish numbers recovered at the end of the cooperation period. The daily net fish production per pond was 352 g on average, which corresponds to a market value of almost 9 000 VND, assuming that the weight gain refers to the grass carp. The conversion of the applied feed (DM) to fish body mass was between 4.6 and 10.6 (or between 4.4. and 8.5 without the consideration of animal-derived manure).

Besides cultured fish, farmers also harvested on average 9.7 kg pond^{-1} (65.1±55.8 kg ha^{-1} year^{-1}) of self-recruiting species such as fish, shrimp, snails, mussels and crabs. These amounts only refer to the self-recruiting species harvested; the amount of self-recruiting species produced in the ponds is likely to be higher. Figure 44 shows the relative composition of cultured fish, self-recruiting species and the total live output of aquatic products during the cooperation period. On average, self-recruiting species made up approximately 3%, whereas the grass carp accounted for over half (~ 52%) of the total live biomass output of aquatic species.

Table 32: Biomasses of in- and outputs in terms of aquatic species (fresh matter), weight gain and food conversion ratio during the cooperation period

	CK1	CK2	SV1	SV2	VL1	VL2
a) Initial biomass[1] (kg)	157.6	98.8	188.8	18.4	114.0	59.3
b) Further stocking[2] (kg)	6.3	1.5	72.0	62.0	0.4	0.0
c) Total removal household consumption (kg)	157.6	151.2	122.1	56.6	17.0	0.0
d) Total removal gifts (kg)	4.5	2.6	2.0	8.3	0.0	0.0
e) Total removal sales before end of cooperation (kg)	136.7	7.9	187.1	45.3	0.0	0.0
f) Total removal other reasons[3] (kg)	7.2	13.0	0.0	13.7	0.0	0.0
g) Total dead fish removed in kg	46.7	56.5	40.6	29.7	0.0	0.0
(of which grass carp in kg)	(46.7)	(53.8)	(37.9)	(29.7)		
h) Total remaining biomass[4] (kg)	27.3	351.7	150.0	140.8	175.4	127.8
i) Harvested biomass SRS (kg)	10.7	10	6.9	29.0	1.5	0.0
Total biomass input ($\Sigma_{a\text{-}b}$; kg)	163.9	100.3	260.8	80.4	114.4	59.3
Total biomass output ($\Sigma_{c\text{-}i}$; kg)	390.7	592.9	508.7	323.4	193.9	127.8
Net gain biomass (k–j; kg)	226.8	492.6	247.9	243.0	79.5	68.5
Total feed applied (kg DM)	2 407.4	2 843.0	1 798.5	2 408.4	623.3	318.0
FCR[5]	10.6	5.8	7.3	9.9	7.8	4.6
Net fish production[6] (kg pond^{-1})	180.1	436.1	207.3	213.3	79.5	68.5
Net fish production[6] (tons ha^{-1})	3.38	3.24	3.57	2.08	1.28	0.66
Net fish production[6] (tons ha^{-1} year^{-1})	1.67	1.75	1.92	1.15	1.62	1.12
Average daily net fish production[6] (g pond^{-1})	244	647	304	324	275	317
Average daily net fish production[6] (kg ha^{-1})	4.6	4.8	5.2	3.2	4.4	3.1

DM = Dry matter; FCR = Food conversion ratio; FM = Fresh matter; SRS = Self-recruiting species
[1]Refers to already stocked fish and fish stocked within the first month of cooperation, real figure might be slightly higher since some fish were probably not netted; [2]Fish stocked after the first month of cooperation until the end of the cooperation period; [3]E.g. use of fish for research purposes; [4]Considers all fish caught at the end of cooperation, real figure might be higher since some fish were probably not netted; [5]Feed and manure applied (kg DM) / net gain biomass (kg FM); [6]Net weight gain = Weight gain – dead fish removed

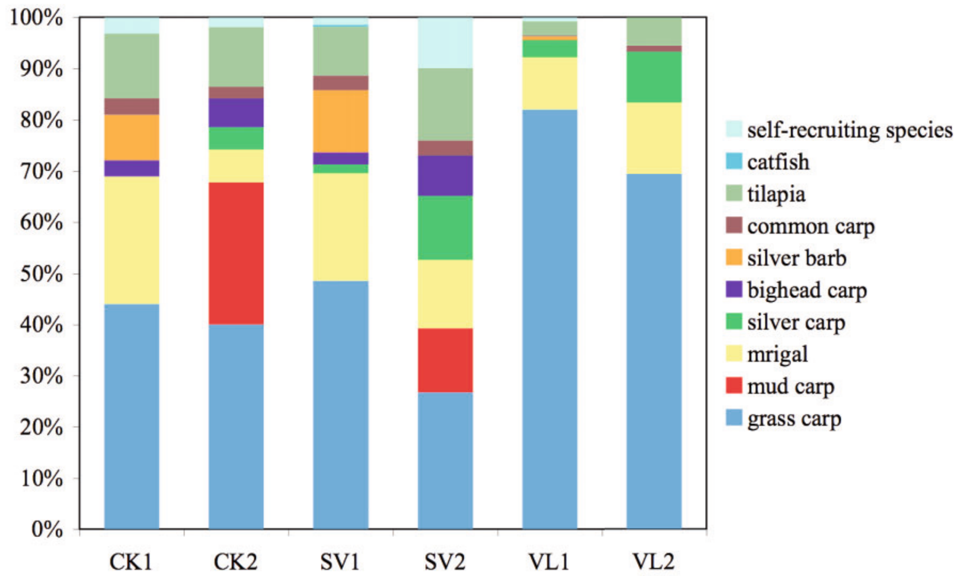


Figure 44: Relative composition of cultured fish species and self-recruiting species of total live output of aquatic products during the cooperation period

6.3.4 Nitrogen balances

In Table 33, in- and outputs in the form of aquatic species as well as feed and manure are shown on the basis of nitrogen (N). While N enters the pond via stocked fish, water, diverse feeds and manure, N exits the system via fish, self-recruiting species (harvested N), water and feed leftovers (non-harvested N). In this calculation, the N entering and exiting the pond via water is ignored. This is due to the before mentioned difficulties in getting reliable data concerning the water amounts flowing through the pond, since there are very high variations among the individual measurements. In addition, the entering of water through the pond bottom (due to the karst character of the region) as well as the leaching of water has not been recorded. This, however, makes it impossible to assess the water-N entering and exiting the pond at an acceptable level.

During the cooperation period, considering only the in- and outputs in terms of fish and self-recruiting species, the average N accretion in the ponds was 5.1±3.5 kg N, corresponding to 39.1±10.6 kg ha^{-1} year^{-1}. The N produced in the form of fish and self-recruiting species made up 14.7% of the total net N applied by feed and manure.

Table 33: In- and outputs in terms of aquatic species as well as feed and manure on the basis of nitrogen (N, kg) over the cooperation period

N source	CK1	CK2	SV1	SV2	VL1	VL2
Inputs						
Fish stocked during cooperation period[1]	3.75	2.29	5.97	1.84	2.62	1.36
Plant-derived feed[2]	55.20	47.82	36.59	33.99	16.45	7.97
Animal-derived manure[2]	6.69	9.25	1.91	6.24	0.03	0.14
Total inputs	**65.64**	**59.37**	**44.46**	**42.07**	**19.09**	**9.47**
Outputs						
Fish removal during cooperation and stock at end of cooperation[1]	- 8.69	- 13.34	- 11.48	- 6.74	- 4.40	- 2.92
Removal of self-recruiting species[3]	- 0.14	- 0.13	- 0.09	- 0.38	- 0.02	- 0.00
Removal of feed leftovers[2]	- 2.30	- 1.00	- 0.80	- 0.34	- 0.67	- 0.30
Total outputs	**- 11.13**	**- 14.47**	**- 12.37**	**- 7.46**	**- 5.09**	**- 3.23**
Ratio Inputs: Outputs	**5.8:1**	**4.1:1**	**3.6:1**	**5.6:1**	**3.8:1**	**2.9:1**
Inputs-Outputs **(kg pond^{-1})**	**54.50**	**44.90**	**32.09**	**34.61**	**13.99**	**6.24**
Inputs-Outputs **(kg ha^{-1} year^{-1})**	**506.4**	**180.5**	**296.6**	**186.8**	**285.1**	**101.9**

[1]Fish assessed with 26% dry matter (DM) of fresh matter (FM) and 8.8% N of DM (Median values in *Cyprinus carpio* as found by Focken and Becker, 1993); [2]N = Crude protein (kg; Table 30) /6.25; [3]assessed with 15% DM of FM and 8.8% N of DM

6.4 Fish growth and feed base of the individual fish species in the ponds

6.4.1 Growth and food conversion of the grass carp

Table 34 shows the biomasses of in- and outputs as well as the gross and net production of grass carp during a defined time period. Pond SV2 is not considered here because of a low grass carp recovery, which was probably caused by the theft of fish to a large extent. The average recovery of live grass carp in the remaining ponds was 78%, ranging from slightly more than 50% in the ponds CK2 and SV1 to a 100% recovery in VL1. In CK2 and SV1, grass carp disease occurred during the period of interest, which most likely explains the low recovery rate. During this time, however, only a fraction of the dead fish appeared and could be removed and weighed. In the pond CK1, grass carp moralities started at the end of the period of interest, which forced the farmers to sell fish ahead of time. In this pond, however, some days after selling big grass carp, another 65 dead grass carp (average weight 568 g) were removed.

One might question the weight of the affected fish in SV2 (560 g) when comparing this amount with the initial fish weight of 625 g (Table 34). This can be explained by the fact that farmers stocked fish of three different size classes (with mean weights of either 400, 600 and 1 000 g), which they obtained from different sources. The fish that were affected probably belonged to the batch of fish with the smaller initial weights; these may have been derived from a neighbouring pond and might have already been infected.

The total weight gain in the ponds was, on average, 1.07±0.11 tons ha^{-1} $year^{-1}$; this number also considers the fish that were dead or missing. The net production that was useable for the farmers was only 0.81±0.27 tons ha^{-1} $year^{-1}$; thus, this accounts for approximately 76% of the grass carp biomass produced.

Grass carp fed voraciously on the majority of the green fodder applied such as banana leaves, cassava leaves and grass material. Some plants, however, seemed to be less palatable for the grass carp including bamboo leaves and the aquatic weed “floating water moss” (*Salvinia natans*). The latter was usually refused by the fish and only consumed in the case of starvation.

Observations of the ponds showed that grass carp were the primary feeders of the applied green plant material. However, other species, especially silver barb, were also observed feeding on weeds and leaves. Assuming that the other fish species had only a negligible effect on the green material consumption and grass carp consumed all of that material applied, 1 kg of grass carp has been produced through the application of 11.8±4.6 kg DM (68.1±17.5 kg FM). The FCR varied enormously from only 4.5 in pond VL2 to more than 20 in pond CK1 (Table 34).

In total, 12 grass carp (average weight 834±326 g and average length 33.7±5.0 cm) from different case study ponds were dissected for examination of the gut content. In all of these cases, the green material applied by farmers was found in the intestines. The relative intestine lengths (RIL) were 2.47±0.31 and the hepato-somatic index (HSI) 1.76±0.35.

Comparing the growth of individual grass carp by taking into account the initial weight at beginning and the final weight at the end of the considered period, disregarding fish removed prior to this time, the average specific growth rate (SGR) was 0.24±0.13% (Table 34). In order to demonstrate the variation in weights of the different individuals, several fish were randomly selected, weighed and measured. The condition factor, however, was the highest in grass carp collected from CK2 and the lowest in those from VL1.

Table 34: Production, food conversion and growth performance of grass carp

	CK1	CK2	SV1	VL1	VL2
Considered period (in days)	May 04- Sept 05 (481)	July 04- May 06 (674)	July 04- Nov 05 (505)	Aug 05- June 06 (289)	Oct 05- June 06 (216)
Biomasses in- and outputs of grass carp (fresh matter)					
Total initial number[1]	210	365	165	126	106
Total initial biomass[1] (kg)	102.9	57.4	103.2	100.8	39.0
Dead fish removed (no)	11	104	62	0.0	0.0
Dead fish removed (kg)	9.8	53.8	34.7	0.0	0.0
Live fish recovered (no)	194	217	87	126	93
Proportion of live fish (no) recovered (%)	92	59	53	100	88
Total biomass output[2] (kg pond^{-1})	180.3	294.3	196.9	159.0	97.3
Total weight gain[3] (kg pond^{-1})	77.4	236.9	93.7	58.2	58.3
Total weight gain[3] (tons ha^{-1} year^{-1})	1.10	0.95	1.17	1.19	0.95
Gross and net production of live grass carp (fresh matter)					
Gross production (live fish, kg pond^{-1})	167.2	214.7	143.3	159.0	88.7
Gross production (live fish, tons ha^{-1} year^{-1})	2.38	0.86	1.79	3.24	1.45
Net production (live fish, kg pond^{-1})	64.3	157.3	40.2	58.2	49.7
Net production (live fish, tons ha^{-1} year^{-1})	0.92	0.63	0.50	1.19	0.81
Food conversion of grass carp					
Green feed applied[4] (in kg DM pond^{-1})	1564	1828	1198	605	261
Green feed applied[4] (in kg CP^{-1} pond^{-1})	292	273	175	98	46
FCR[5]	20.2	7.7	12.8	10.4	4.5
PER[6]	0.27	0.87	0.54	0.59	1.27
Growth of individual grass carp (all fish considered)					
Initial average weight of individual fish (g)	490	157	625	800	368
Final average weight of individual fish[7] (g)	836	1 017	1 731	1 296	954
Weight gain individual fish (g)	346	860	1 106	496	586
SGR (%)	0.11	0.28	0.20	0.17	0.44
Fish weights, lengths and condition factor of a sample[8]					
Sample size	15	24	8	14	13
Final average weight ± SD	923±547	831±438	1 233±668	1 071±268	907±330
Final average length ± SD	35.7±5.6	33.6±6.2	38.6±9.0	39.7±5.2	35.9±4.9
Mean condition factor ± SD	1.85±0.37	2.06±0.37	1.89±0.14	1.73±0.29	1.91±0.25

CP = Crude protein; DM = Dry matter; FCR = Food conversion ratio; GC = Grass carp; PER = Protein efficiency ratio; no = number; SD = Standard deviation; SGR = Specific growth rate
[1]Refers to grass carp (GC) stocked at the beginning of the considered period and GC additionally stocked within the first month; [2]Biomass includes final GC biomass, live and dead GC removed over the considered period and GC missed; number of missed GC = initial GC no – dead GC removed – final GC no; weight of missed GC = (average final weight + initial weight) / 2; [3]Weight gain = Total biomass output – total initial biomass; [4]Considers only green plant parts applied (leaves and grasses) during the considered period; [5]FCR = Green feed applied (kg DM) / Total weight gain (kg); [6] PER = Total weight gain (kg) / crude protein (of the green feed) applied (kg); [7]Average body weight of fish harvested at the end of the considered period; [8]Randomely collected fish by counting at end of considered period, total = all GC, except in the case of SV1 (fish collected from one harvest day only)

6.4.2 Growth and feed of the other fish species in the polyculture ponds

The relative composition of live fish species produced over the cooperation period is shown in Figure 44. On average, 38.5% of the fish biomass at the beginning of the cooperation period was made up of non-grass carp species. For the entire live biomass output, the proportion shifted to 48.2%. To some extent, this was caused by the diseases that affected the grass carp. In the two ponds without diseases (VL1 and VL2), there was not a big shift in the proportion of the grass carp.

It was comparatively easy to determine the growth rates of the individual grass carp since relatively few fish were removed for household consumption and a relatively high share of dead fish could be recovered and weighed. In contrast, the frequent removal and restocking of the other fish, as well as the ability of the tilapia and common carp to reproduce in farmers' ponds, made it extremely difficult to assess the individual growth of those species. An example of this is as follows: a farmer stocks 100 fish from different sources and of different size classes, he removes 70 for consumption and finally recovers 12 fish. Calculating the SGR based on the average initial and final weights, for example, is probably not correct, since it is impossible to allocate the fish recovered at the end to the size class stocked at the beginning. For a correct estimation of the growth rates, either a marker has to be used or the removal of fish must be suppressed during the period of observation. However, interference in farmers' activities was avoided during the study period.

In the following paragraphs, only some examples of growth rates are given from periods with relatively little removal of fish. However, the data will give a rough idea concerning the fish growth but have to be evaluated with care.

Mud carp and mrigal play the second largest role in farmers' ponds and made up, on average, 22% of the live fish biomass output (Figure 44). Mrigal were grown from 271 to 642 g in pond CK1 (481 days; SGR: 0.18%) and from 196 to 457 g (216 days; SGR: 0.39%) in pond VL2 respectively. The mud carp in CK2 grew from an average 69.9 g to 815 g (674 days, SGR: 0.36%). Both mud carp and mrigal had long intestines, being on average almost 16 and 17 times the size of their respective standard body lengths (Table 35). A look into their intestines showed a high abundance of mud. However, when checking the intestine contents under the microscope, besides considerable amounts of detritus, a number of phyto- and zooplankton as well as pieces of a crab were also found (Table 36).

Silver carp and bighead carp made up only 8% of the total live biomass output (Figure 44). The silver carp grew from 314.6 to 445 (289 days, SGR: 0.12%) in VL1, the bighead carp from 47.9 to 1111 g in pond CK2 (674 days, SGR: 0.47%) and from 150 to 497 g in CK1 (481 days; SGR: 0.25%). The silver and bighead carp sold were typically marketed with average body weights greater than or equal to 1 kg. The lengths of the intestines of the silver carp were almost 7 times their body length (Table 35) and the food items recovered from the intestines of these fish species included phytoplankton as well as detritus (Table 36). However, zooplankton and some benthic animals were also found. In the case of bighead carp, besides zooplankton and detritus, phytoplankton and pieces of crabs were also recovered.

Tilapia accounted for 9% of the live fish output over the cooperation period. These fish rarely exceeded a body weight of 100 g; the usual weight of tilapia harvested for consumption ranged between 30 and 50 g per fish. The intestines of tilapia were on average 8 times the size of their respective body length (Table 35); typical items found in the intestines were phytoplankton and detritus (Table 36). While a few common carp with average body weights of half a kilo were caught, the recovery rate itself was very low. Items found in the intestines of common carp comprised detritus, plant material and small fish (Table 36).

Silver barb grew from 1 to 28.1 g in pond CK1 (481 days, SGR: 0.69%), from 72.3 to 432.2 g in SV1 (505 days, 0.35%) and from 20 to 163 g in pond VL1 (289 days, SGR: 0.73%). Food items recovered from the intestines of the silver barb included mainly phytoplankton and detritus (Table 36).

In farm SV1, the farmer stocked 8 catfish. However, only 1 catfish was harvested (1.5 kg), while 4 dead fish were removed in the wintertime and 3 fish were not recovered.

Even though the data from farm SV3 is not presented in this book, the special feature that this farm produced pirapitinga is again worth mentioning in this context. Farmers stocked 160 fish (average weight 18.1 g), harvested 96 fish for household consumption (average weight 254 g) and sold 28 fish (weight 310 g). Considering the weight at time of harvest, the SGR of these fish was 0.5%. Examination of the intestines of two pirapitinga showed that these fish consumed fruit that had fallen from trees surrounding the pond (Table 36). However, detritus as well as small fish and zooplankton were also abundant in their intestines.

Table 35: Relative intestine length (RIL) and hepato-somatic index (HSI) of different fish species caught from the case study ponds

	Samples	Body weight (g)	Body length (cm)	RIL	HSI
Mrigal	5	199.4±116.3	22.1±4.3	17.30±2.45	1.50±0.15
Mud carp	5	434.6±362.7	25.2±9.9	15.94±3.57	1.07±0.36
Silver carp	8	483.6±335.6	27.8±6.8	6.78±1.31	0.84±0.19
Common carp	2	150.8±63.4	18.5±2.1	1.88±0.49	0.84 (1 fish)
Silver barb	5	168.7±129.1	17.3±3.6	2.64± 0.51	1.25±0.12 (3 fish)
Tilapia	7	61.9±43.9	11.8±2.9	8.27±2.54	1.28±0.44 (5 fish)

Table 36: Intestine contents found in different fish species caught in the case study ponds

	Phytoplankton								Zooplankton			Benthos			Others		
	Bacillariophyceae	Chlorophyceae	Euglenophyceae	Cyanophyceae	Dinophyceae	Xanthophycae	Chrysophyceae	Rhodophyceae	Cladocera	Copepoda	Rotifera	Mollusca	Decapoda macrura	Decapoda brachyura	Organic detritus	Fresh plant material	Small fish
Mud carp	x	x	xx	xxx					xx	x					xxx		
Mud carp	x	x	x			x			x						xxx		
Mud carp	x	x	xxx		x						x				xxx		
Mrigal	xx	x	xx	xxx	x						x				xxx		
Mrigal	x	x	xx	xxx	x	x				xx				x	xxx		
Bighead carp	xx	xx	xxx	x	x				x	x	xx				xxx		
Bighead carp	xx	xx		xx		x			xxx	xxx					xxx		
Bighead carp	xx	xxx	xx	x					xx	xx	x				xxx		
Bighead carp	xx	xx		xx					xx	xx	x			x	xxx		
Bighead carp	x	x	x	x				x	xxx	xx	x				xxx		
Silver carp	x	xx	xxx	xxx					xx	xx			x		xxx		
Silver carp	x	xx	xxx	xx	xxx	x			x		x				xxx		
Silver carp	xxx	xxx	x		xx				x		xxx				xxx		
Silver carp		xxx	xxx	xxx					x	x	xx		x	x	xxx		
Tilapia	xxx	xx	xx	x	x						x				xxx		
Tilapia	x		x	x				xxx	x	x	x	x			xxx	x	
Tilapia	xx	xx	xxx	xx	x						x				xxx		
Tilapia	xxx	xx	xxx	xx							xx				xxx		
Tilapia	x	xx	x	x	xxx										xxx		
Silver barb	xxx	x	xxx	x	xx						x				xxx		
Silver barb	x	xx	xx			x									xxx		
Common carp	x		x		x										xxx		
Common carp															xxx	xx	x
Common carp															xxx		
Pirapitinga	x	x		x		x	x		xxx	xxx				x	xxx	xx*	xx
Pirapitinga															xxx	xx*	

Ranked according to visual abundance under the microscope: x = low abundance, xx = medium abundance, xxx = high abundance; *Parts of fruits and kernels of tamarind

6.5 Benefit from fish production - Income and household consumption

6.5.1 Fish sales: Quantities and revenues

Table 37 shows the fish sales after the major rearing period from the case study ponds. Considering the time period from the purchase until the sale of the major fish amounts, on average, farmers raised fish for 21±7 months. Since farmers partly raised fish in their nursery ponds prior to this time, the rearing period of these fish at the farm was even longer. The relatively short rearing periods in SV1 and VL2 are due to the fact that grass carp were stocked at comparatively high initial weights. The average quantity of aquatic products sold after the major rearing period was approximately 200 kg pond^{-1} (1.3±0.7 tons ha^{-1} year^{-1}) and ranged from only 41.4 kg in pond SV2 to approximately half a ton in pond CK2. Farmers' mean revenues from fish production were 4.3±3.2 mil VND per pond, which corresponds to 29.0±16.1 mil VND ha^{-1} $year^{-1}$.

On average, grass carp accounted for 62% of the total fish mass that were marketed. Figure 45 demonstrates the species composition of fish sold in two ponds. Grass carp were sold with mean sizes ≥1.2 kg and fetched prices from 22 000 to 25 000 VND kg^{-1} (Table 37), depending on the size of the individual fish as well as the point of sale. Fish marketed directly usually fetched higher prices. However, the prices also depended on the abundance of other retailers at the respective time, which explains the comparatively low price of grass carp marketed directly by SV2. In addition to selling fish at market size, two farmers sold small fish to other farmers for further rearing.

Table 37: Fish sales after the major rearing period from six case study ponds

	CK1	CK2*	SV1	SV2	VL1	VL2*
Time of harvest for sales	Sept 05	Oct 06	Nov 05	Oct 05	Jun 06	Dec 06
Proximate major rearing period in months (days)[1]	29 (878)	27 (827)	16.5 (505)	14 (430)	26 (793)	14 (427)
Sale of cultured fish (kg)	134.0	495.0	187.1	35.4	152.0	183.0
Of which: sale of grass carp in kg (in %)	86.2 (64%)	280.0 (57%)	122.9 (66%)	18.5 (52%)	113.0 (74%)	108.0 (59%)
Sale of SRS (kg)	6	3	6.9	6	1.5	n.d.
Total sales in tons ha^{-1}	2.6	3.7	3.3	0.4	2.5	1.8
Total sales in tons ha^{-1} $year^{-1}$	1.1	1.6	2.4	0.3	1.1	1.5
Average size of grass carp (mud carp/mrigal) sold	1.2 (0.7)	1.4 (1.0)	1.7 (0.6)	1.2 (0.3)	1.6 (0.5)	n.d.
Price 1 kg grass carp (mud carp/mrigal) in 1 000 VND	23 (18)	22-23** (18)	25 (20-22**)	24 (22)	22 (22)	22 (18)
Point of sale	Trader + farmers	Trader	Market	Market + farmers	Trader + Market	Trader
Total revenues (in 1 000 VND)	2 873	10 270	4 412	734	3 326	3 926
Total revenues (in 1 000 VND ha^{-1} $year^{-1}$)	22 408	33 650	54 981	6 061	24 692	32 425

SRS = Self-recruiting species; VND = Vietnamese Dong
[1]Time period from the purchase until the harvest of the major fish amounts
*Information based partly on statements of farmers gathered after completion of the cooperation period; **Prices differed according to individual fish sizes

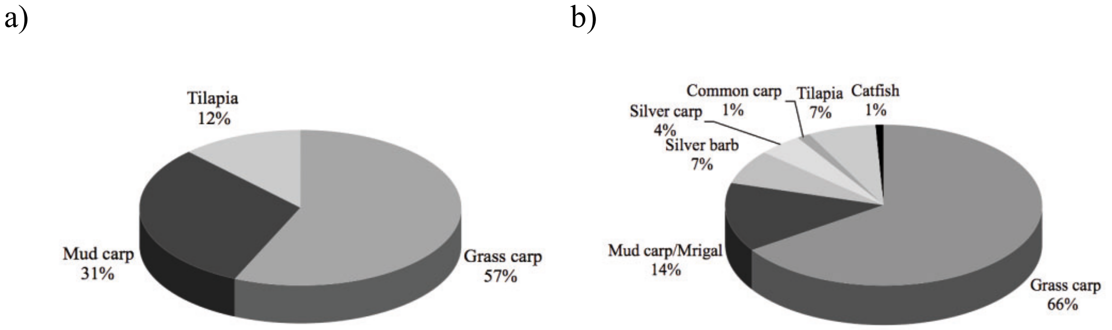


Figure 45: Species composition of cultured fish sold from case study ponds (a) CK2 and (b) SV1 on the basis of biomass (fresh matter)

6.5.2 Household consumption of fish: Quantities and species

Average monthly household consumption of cultured fish and self-recruiting species from the ponds varied between 0 and 7.2 kg (see Table 38). Three farmer households (SV2, VL1, VL2) also harvested fish from other ponds, which could not be quantified. Reasons for smaller harvests of fish for household consumptions include a) small fish size (SV2) and b) a relatively far distance between the household and the pond and therefore a high time requirement (VL1). In the case of VL2, the farmers reared fish in the respective pond exclusively for income generation.

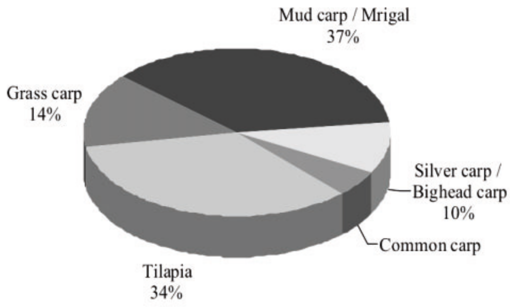
For the remaining farmers' households (CK1, CK2 and SV1), the ponds studied were the only source of aquatic products. In their cases, the monthly consumption was 5.6 to 7.2 kg per household; the monthly consumption per household member was close to 1.2 kg. Figure 46 shows the proportion of different fish species consumed within the household in the case of two farms (CK2 and SV1). Tilapia and mud carp or mrigal were the major species consumed respectively. Fish, just like other food items, were eaten together by all family members, which pointed to an equal intra-household food distribution among gender within the Black Thai households.

Table 38: Average monthly consumption of aquatic products (in kg) from the investigated ponds during the cooperation period

	CK1	CK2	SV1	SV2	VL1	VL2
Consumption per household	6.8	7.2	5.6	3.6	1.8	0.0
Consumption per capita	1.4	1.2	1.1	1.2*	0.5**	0.0

*Only three household members are considered, since the two other members usually did not participate in the household meals during the cooperation period; **4 household members are considered, household size changed during the cooperation period

a) b)



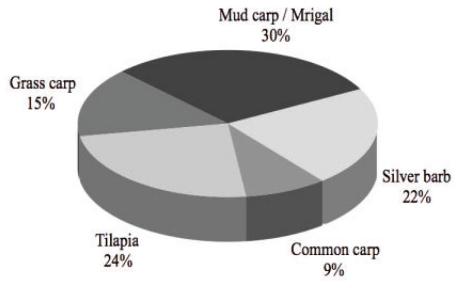


Figure 46: Species composition of cultured fish consumed from case study ponds (a) CK2 and (b) SV1 on the basis of biomass (fresh matter)

6.5.3 The farm incomes

The household income of farmers as well as the income exclusively from fish production for 2004 are shown in the Tables 20-22 and is based on statements from farmers. In order to verify the cash income of the farmers in 2005, the cash flow of each farmer was recorded over the year and is compiled in Table 39. The average cash income from exclusively farm activities was 17.6±9.2 mil VND. This figure does not consider additional expenditures paid by farmers, e.g. the taxes that have to be paid for residential land (typically being around 20 000 VND year^{-1}) and payments to unions (e.g. farmers' union, women's union, union of elderly people, etc.) and funds (e.g. for poor people, flood, etc.). In addition to the income from the farms themselves, two farms received a considerable amount of additional income from off-farm activities. In SV1, for example, this was due to an extra high salary of the cooperation farmer's wife, who worked as a teacher in a remote area. The income from fish production accounted for 12.4% of the on-farm income. The low income in fish production in VL2 was due to high grass carp losses caused by disease(s).

It should be considered that revenues and costs are highly variable over the years. Selling a buffalo, for example, considerably increases the total revenues of a farm. Crop seeds are not purchased yearly, the same being the case with the purchase of young fish. The figure in Table 39 refers only to cash income and completely neglects household consumption of the produce. Rice, for example, is only marginally represented in the figure since it is usually exclusively consumed within the households. Also, the farmer at VL2 transformed a part of his paddy fields into ponds; therefore, the farmer's rice supply is not sufficient enough to cover the family's requirements. Thus, the farmer has to buy rice from his income, which is also not represented in this figure. Comparing income from the cash crops with income from fish is also difficult, since in the case of fish, a high share of the yields is consumed within the household while cassava and maize are almost exclusively sold to markets.

During the study period, major expenditures of the cash surpluses from the farms were spent on karaoke equipment, televisions, furniture and reparation of the houses. The high income from SV2 was used for the construction of a new house for the farmers.

Table 39: Cash flows (in 1 000 VND) from crop, livestock, fish production and off-farm activities in 2005 in the case study farms

	CK1	CK2	SV1	SV2	VL1	VL2
Crop production						
Maize	4 320	5 760	4 000	2 200	12 000	10 500
Cassava	1 560	1 200			1 400	330
Rice			2 760			
Banana	180	480	140		300	35
Mango	84	3 500	600	21 000	600	150
Tamarind	390	400	450		60	56
Litchi		250				
Pomelo		150				
Vegetables		300		1 500		700
Cotton			1 740			
Fertilizer (P, N, Urea)	- 870	- 1 690	- 1 750	- 950	- 1 052	- 800
Seeds (e.g. maize, rice)	- 371	- 310	- 494	- 142	- 806	- 312
Pesticides			- 40	- 75	- 28	- 18
Irrigation fee	- 86	- 18	- 100	- 62	- 27	- 12
Total income (crops)	**5 207**	**10 022**	**7 306**	**23 471**	**12 447**	**10 629**
Livestock production (without fish production)						
Large ruminants	3 500			5 000		4 800
Small ruminants		2 340		1 500	500	1 040
Poultry		2 160	1 200	3 000		875
Medicine for livestock			- 15	- 20	- 20	- 10
Poultry fodder					- 400	
Total income (livestock)	**3 500**	**4 500**	**1 185**	**9 500**	**80**	**6 705**
Fish production (all ponds together)						
Fish sales	2 873		4 412	3 000	3 300	1 540
Fish seed purchases	- 252		- 2 120	- 450	- 130	- 1 115
Total income (fish)	**2 621**	**0**	**2 292**	**2 550**	**3 170**	**425**
Total on-farm income	**11 328**	**14 522**	**10 783**	**35 521**	**15 697**	**17 759**
Off-farm income	**6 000**		**34 000**			

6.5.4 Profitability of fish production

In all case study farms, farmers consider fish production to be a highly lucrative business. In order to evaluate the profitability of the case study ponds, all costs and benefits related to fish production over the cooperation period are compiled in Table 40. While some of the costs and benefits have been calculated based on money that has been effectively paid or received, other entries are based on the opportunity costs.

Prices of fish that were not purchased or sold within the cooperation period were assessed at 20 000 VND kg^{-1} in the case of small fish and fish consumed within the households, while the fish at the end of the considered period (“remaining fish”) were assessed at 22 000 VND kg^{-1}. This reflects the fact that smaller fish usually fetch lower prices compared to big fish and that a higher proportion of the fish consumed within the households consists of the low-value tilapia. The “remaining fish” usually comprise bigger fish and a higher share of high-value fish such as grass carp.

Some of the applied feeds have real market prices, which have been used in this calculation. The majority of the feed (leaves and weeds), however, does not fetch prices on the market and is generally not scarce (with minor exceptions, e.g. during wintertime). Since the feed collection requires labour, the feed costs are assessed based on labour requirements. Labour is valued according to the theoretical income that farmers would receive if they worked off-farm instead. Since manure may be applied to the crop fields instead of using it as pond input, its value is assessed on the basis of its value as fertilizer in the form of nitrogen.

The investment costs for fishing gear were not considered in this calculation, since gear is usually shared among different ponds and farmers and is sometimes used over several decades. No taxes or irrigation fees are paid for ponds. Water is not assessed by its opportunity costs (e.g. use of water for paddy fields instead), since farmers are usually not able to direct the water to their crop fields instead of to the ponds.

The average profit of fish production was roughly 1.15 mil VND $year^{-1}$ per pond. Each farm had a profit from its pond; even SV2 experienced a profit despite theft of fish and mortalities of grass carp. Based on the hours of labour spent on pond purposes, farmers produced an average value of 5 700 VND $hour^{-1}$.

Table 40: Profitability of the fish production during the cooperation period (values in 1 000 VND)

	CK1	CK2	SV1	SV2	VL1	VL2
Total revenues of fish and SRS sold	2 932	182	4 412	952	3 326	0
Market value of fish consumed by the household[1]	3 152	3 024	2 442	1 132	340	0
Market value of the remaining fish[1]	858	8 081	3 344	3 582	515	2 812
Market value of SRS consumed[1]	47	100	0	230	0	0
Costs of fish purchased at beginning of cooperation		- 1 263	- 2 160			- 1 115
Proximate marked value of other fish stocked[2]	- 3 278	- 1 066	- 3 356	- 1 608	- 2 288	- 208
Labour costs[3]	- 2 303	- 3 897	- 2 731	- 2 913	- 873	- 866
Manure costs[4]	- 27	- 37	- 8	- 26	0	- 1
Marketable feed[5]	- 93	- 222	- 59	- 843	- 2	- 10
Profit in total[6]	1 288	4 902	1 884	506	1 018	612
Profit[6] ($pond^{-1}$ $year^{-1}$)	638	2 655	1 010	281	1 286	1 034
Profit[6] (ha^{-1} $year^{-1}$)	11 968	19 708	17 410	2 730	20 737	9 992
Value of production per man-hour[7]	5.0	7.3	5.4	4.6	6.8	5.4

SRS = Self-recruiting species; VND = Vietnamese Dong

[1]Fish prices: 20 000 VND kg^{-1} in the case of household consumption, 22 000 VND kg^{-1} for remaining fish, 10 000 VND kg^{-1} for SRS; [2]Costs of fish are assessed as follows: 1 kg fish = 20 000 VND; [3]Labour costs are assessed as follows: 8 labour hours = 1 day off-farm work = 25 000 VND; [4]Manure costs are assessed as follows: Manure → 1.4% N of DM; 1 kg of N = 4 000 VND (approximate market price in 2005); [5]Marketable feed calculated with the following market prices: 1 kg rice bran (low quality) = 1 200 VND; 1 kg chopped cassava tubers = 1 300 VND; 1 kg maize meal = 2 000 VND (approximate market prices in 2005); vegetable tops not considered (unmarketable surpluses); [6]Profit = total value of fish produced – total costs;[7]Value of production per man-hour = (total value of fish produced – total value of fish stocked) / total labour hours

7 Discussion

7.1 Discussion of the methodologies applied

7.1.1 Macro level: Choice of the study area and dimension of aquaculture in the region

The study was carried out in Yen Chau district, which is located in the northern Vietnamese mountains. The population in this region suffers from poverty as a result of its geographic isolation, limited land area, poor communication and transportation infrastructure, poor public and extension services including health and education and restricted access to market and credit services. Similarly, the supporting policies and assistance from the government experience difficulties in reaching the local level in these areas (Luu, 2001a). The isolation of this region might partly contribute to the fact that, so far, not much data from this region has been published for an international audience.

In the Yen Chau district, aquaculture plays an important role. Despite its importance, little is known about fish production in the upland areas of this region. It has been mentioned in some publications that aquaculture takes place here (Dien and Quynh, 2001; Luu, 2001b), but none of these publications provided any science-based data on the system. The fact that the local aquaculture system exhibits features that are rather atypical for carp polyculture systems of other regions (e.g. a more or less constant water flow) and that poor farmers in the region may directly profit from developed improvement measures makes this district a favourable place for carrying out the research.

The study concentrated on communes where a large proportion of farmers practiced aquaculture. According to the statements made by the village headmen, over 63% of the households in the studied communes produce fish in ponds. However, it is assumed that this figure is slightly overestimated. When the village headmen were queried regarding the percentage of village households involved in fish farming, they frequently replied, that "all farmers produce fish" to demonstrate the importance of fish production in the village. Whether all farmers produce fish in reality has not been explicitly clarified. Furthermore, the pond area per household interviewed was 1 267 m^2 on average (survey 1 and 2); this figure is considered to be quite reliable. In contrast, the average pond area, as calculated from the headmen's statements, was only 970 m^2, indicating that perhaps the number of farmers has been overestimated or the pond area is larger than what is known by the local authorities. The pond area per household, as provided by the Statistical Office Yen Chau (see 2.2.6), however, was much lower (445 m^2) as was found in the present study. In contrast to the above-mentioned data, the basis for the assessment of those statistics was the whole district that includes even those communes with a lower impact and importance of aquaculture. Nevertheless, pond sizes are probably much larger than what has been reported to the official offices. The referenced pond sizes are often based on entries in the "Red Book", and sizes can deviate from reality due to ex-post enlargements, for example. Some ponds are not recorded at all, e.g. in the case that they were illegally built. This was frequently observed during the study period.

The sites of research were the communes located near the district town of Yen Chau, where many farmers produce fish. In the more remote and hilly areas, however, little aquaculture is practiced. Here, the setting differs greatly from the area studied, which is partially caused by lower availability of water as well as longer routes for transport and limited access to markets. While the chosen communes might not be fully representative of the whole district (which also comprise hilly areas, for example), it is probably quite representative of the irrigated regions in the less remote areas of the region. Even though those investigations were not explicitly part of the presented research, ponds in other communes and districts were also observed and farmers were questioned about their pond management practices.

The case study farms were selected after carrying out the first interview survey with 70 interviews (survey 1). After each individual interview, visits to the pond sites were undertaken. Farmers usually presented just one of their ponds, which was typically the pond that was located nearest to the farmers' houses. These ponds were usually located in the residential and paddy field areas, which was the reason for choosing the first six case study ponds in those areas. Finally, with the evaluation of the data gathered through standardised interviews (survey 2), it became apparent that also ponds in the upland areas (that are usually located farther away from the farmers' houses) play a very important role. For this reason, the three case study ponds in the upland areas were selected at a later date of the present research.

7.1.2 Meso level (interview-based surveys): Use of one-time interviews and long-term survey of case study farms

The first interviews (survey 1) were carried out in villages that were suggested by the local extension service. Besides a high importance of aquaculture in those villages, the personal relations between the extension workers and the village headmen probably served as selection criteria. This could have similarly been the case when the village headmen recommended farmers for interviewing: often these were either relatives or important members of the village society (e.g. heads of unions). In order to avoid the description of “the pond system of the richest”, the pond management of other farmers in the region was observed and farmers were selected randomly for the questionnaire survey (survey 2). Survey 2 was required to quantify the collected information on a broader and more standardized level. The high importance of the upland ponds, for example, which was described in the previous chapter, would have probably not emerged without the questionnaire survey.

Major difficulties during the interviews were issues such as the association of information with the individual ponds. Due to the fact that most farmers own several ponds, confusion arose when associating fish stocks or fish yields with the individual ponds. Therefore, the ponds had to be “named” with the farmers’ terminology but further inquiries were usually necessary to associate the information with the right pond. Also, misunderstandings between researchers and farmers arose either as a result of the translations or due to the local terminology, which was referenced in chapter 5.1.2. All of this required some extra time for clarification.

The case study farms were selected after the completion of survey 1. One of the criteria for the final selection of a farmer as a cooperating partner was the predictability of long-term cooperation assessed according to the farmer’s interest in fish production and research. In this way, farmers were evaluated in a relatively subjective manner. Thus, progressive farmers with a heightened interest in their ponds as well as research were predominantly selected. That aquaculture plays a relatively important role for the selected farmers was clear when the average numbers of ponds owned by them (2.7) is compared with those from the interviewed farmers (1.6); this is also the case when observing the proportion of income from fish sales in 2004 (17% as compared to 12% in interviews). It is likely that farmers with a higher interest in their aquaculture activity also put more effort into their ponds, which may be reflected in above average fish yields. However, the overall pond as well as farm management of the case study farms did not differ from that of the farmers in the survey.

The total period of the present study lasted over two years. By personally observing the farming practises and regularly interviewing the case study farmers year round, a clear understanding of the pond and farming systems in the region was obtained. Problems and occurrences that were not noticed during the formal one-time interviews were identified and recorded.

Often, the season in which farmers were interviewed influenced their answers. When asking farmers about typical fish feeds during the maize production period, they would state maize leaves as being a very important input, but they might not even mention this feed item in an interview during the other times of the year. Other answers that were probably influenced by the season include the time when farmers were asked to rank potential problems connected to fish production in the summer of 2005. In that respective year, a shortage of water was a severe problem, which resulted in a high ranking of this problem. In contrast, fish mortalities caused by low water temperatures were ranked low in the summer interviews since it is typically a winter problem. Besides the fact that the seasons as well as current activities influenced the answers in the interviews, farmers sometimes described the "optimal" situation rather than the "typical" situation. It occurred, for example, that farmers mentioned lime as being an important input to their ponds, but it appeared later that farmers had no access to it.

In order to gain further insight into local fish production, observations in addition to the interviews during several seasons in the year were necessary. Upon asking farmers whether they usually have enough fish feed during the year, they typically affirm this. In the winter, it could be observed that some farmers did not apply feed to the ponds over the course of several days since the amount of leaves and weeds used as fish feed were limited. Additionally, some farmers stated that they avoid feeding duckweed that has been sprayed with pesticides; however, it was observed that duckweed was collected from shared canals. Thus, it cannot be excluded that this duckweed was not contaminated prior to its collection.

By means of long-term cooperation with farmers of the case study farms, mutual trust developed, which enabled access to information that is usually off the record. This includes information about illegal practices, such as the use of well water for pond watering purposes, use of officially banned rodenticides or illegal use of paddy fields as ponds. Long-term communication also reduced the number of biased answers that researchers obtained from farmers.

Both the long-term cooperation as well as the one-time interviews were necessary in order to adequately understand the aquaculture system. The interviews on a broader basis (survey 2) provided information concerning the representation of the case study farms (e.g. pond location), whereas the long-term cooperation with the farmers assisted in being able to better evaluate certain topics that came up in the interviews (e.g. ranking of problems).

7.1.3 Micro level (measurement-based survey): Potentials and limitations in gathering measured data from the case study farms

By collecting data on the micro level, data that was not accessible through interviews alone could supplement the findings. Estimating reliable fish yields and growth rates in ponds, for example, is difficult - if not impossible - with interviews alone. Fish are regularly transferred from one pond to another, with different sizes stocked from different sources at different times and are frequently harvested for household consumption. Altogether, this leads to constantly changing stocking densities, which makes it extremely difficult for farmers to estimate current fish amounts. In addition, farmers usually do not take notes about their pond farming activities; thus, they are often not able to remember the stocked or harvested amounts. Upon inquiring about fish yields, farmers frequently refer to yields of grass carp only, since the grass carp tend to be the most important species for marketing, and neglect the yields of all other fish species. In particular, the production of tilapia and common carp is often not mentioned at all, probably due to the fact that these fish species are self-recruiting within farmers' ponds so it is practically impossible to estimate their amounts.

Even though the data collection on the micro level provided quite reliable data with the use of record books and measurements for the selected ponds, a number of difficulties arose, which derived from the cooperation with the farmers as well as from the measurements themselves. The goal of the present study is to describe the aquaculture system and to reveal potential ways of improving the system. Therefore, the activities of farmers were only observed and any kind of interference was avoided as much as possible. Since interference was discouraged, requests to the farmer to alter normal aquaculture practices and time management could not be made; it was therefore impossible to select farms that fulfil the selection criteria defined and that all stock and harvest fish at around the same time. For the different rearing and cooperation periods, all of the data had to be converted in order to correspond with a hectare and year for better comparability. Therefore, farms are compared on the basis of varying initial fish weights, pond sizes, rearing periods, etc. These variables contribute to the different pond productivities found in the case study ponds.

Differences between the productivity can also be attributed to other factors such as the amount and composition of the feed applied to the pond as well as the types of water sources. High variations in pond productivities are very common in aquaculture research and the underlying causes often remain obscure (Edwards et al., 1996a). Edwards et al. (1996a) state that there might also be factors such as variations in silt content in the water as well as iron and aluminium content of sediments, which all might influence productivity.

Differences in the pond productivities may further be related to the behaviours of the individual farmers as well as their social status. In the case study farms, the younger farmers, spent less time on their ponds due to heavier workloads in the fields. This is only partly represented in the daily labour input (Tables 20-22), which mainly refers to the time spent “effectively” for pond-related purposes (e.g. feed collection and application). Elderly farmers (e.g. the relatively old farmer of CK2), who usually do not participate in the physically demanding field work, spent much more time at the pond site “looking after the fish” in contrast to the relatively young farmers (e.g. the farmer of SV2). Better supervision of the pond may also be linked to the location of the pond; a pond near the house is comparatively easy to observe as compared to ponds situated far away.

The productivity, as expressed in the net fish production, deviated 71% between the lowest (1.12 tons ha^{-1} $year^{-1}$) and the highest (1.92 tons ha^{-1} $year^{-1}$) yields among the case study ponds. Although the difference between the individual ponds may be considered high, especially when taking account the value of fish in relation to farmers’ incomes, the difference does not play an important role when comparing aquaculture systems with each other. The annual net production of 1 to 2 tons per hectare is generally low when compared with the yields reported from other feed-based systems. Therefore, despite the differences among the ponds, the data shows definite uniformity.

On-farm studies have to fit into the farmers’ normal schedule of activities. Scheduling important procedures such as stocking or harvesting, was often difficult. Arranged dates were frequently not maintained. Pre-fixed harvest dates, for example, had to be frequently postponed when either no new water was available or draining was not possible due to certain activities in the adjacent fields or ponds. It was also the case that farmers stocked or harvested a portion of their fish prior to the arrival of the researchers. This was the case when farmers had access to juvenile fish on short-term notice or when they harvested big fish due to apace cash requirements or social events, such as funerals, religious ceremonies etc. In the case of SV2, for example, farmers planned to harvest fish at a much later point in time, but they urgently required money for their house construction so they prematurely harvested a portion of their fish. Also, the sudden death of a household member of SV3 required the supply of food for the mourners. In these cases, the data (fish weights and amounts) was provided by the farmers. Since farmers have been provided with scales, they were able to weigh the fish and they usually immediately recorded the fish weights (with the exception of certain farms that were not considered on the micro level). The data from the farmers’ notes seemed to be quite reliable.

Since interference was kept as low as possible, the harvest of fish for household consumption was not suppressed. The stocking of different size classes and frequent removal of fish made it difficult to estimate the growth rates of the individual fish in the ponds as has been described in chapter 6.4.2. For determining the real growth rates, the conditions need to be more controlled and farmers' behaviours should be aligned with the requirements of the researchers.

The maintenance of the farmers' record books was performed correctly most of the time during the study period. However, they were neglected or poorly managed in times of very high labour peaks, such as during rice harvesting. Also, social challenges partly hindered farmers' abilities to maintain the notes. This was the case with SV2, for example, when a household member was in hospital for a week. During these days, the cooperation partner was unable to update the book.

Even though farmers were trained and visited regularly, it probably occurred that feed amounts were only estimated or some minor inputs were neglected. For example, the application of fermentation residues from the distillation of liquor was frequently added to the ponds. Since the amounts were low and not considered to be important by the farmers, it occurred that farmers "forgot" to include those inputs. Also, certain inputs were not weighed but estimated instead. This occurred, for example, when farmers collected animal droppings from a nearby road and just put them into the pond. Although the notes in the farmers' books may only give rough estimates of the real amounts, they are probably much more reliable than data gathered through interviews alone, especially when assessing the average amounts of feed year round and not only during the season of the interviews.

Compared with terrestrial animals, it is extremely difficult to gain an accurate overview of aquatic animals, since they are not easily visible and countable; this makes aquaculture research especially difficult. For example, it occurred that fish were lost in the case of farm VL3, which has neither been realized by the farmer nor by the researchers. The occurrence of uncertainties such as theft or floods made the evaluation of the data from VL3 impossible. Also, in the case of SV2, due to theft occurrence, not all data could be evaluated.

Although not all data could be gathered satisfactorily on the micro level due to the "uncontrolled" conditions, the data provided from these observations supplements the data gathered from the interviews. The case study ponds are representative of the interviewed farmers' ponds since all ponds are managed in a similar way. Also, certain figures including the average amounts of fish sold or consumed within the household were quite similar in both surveys. The use of measured data and the records kept by cooperating farmers in connection with the long-term observation of the case study farms and their neighbours in addition to the data collected from the interviews with farmers and other resource persons led to the creation of a database that is able to describe the aquaculture system in a holistic way.

7.2 Classification of the aquaculture system

7.2.1 The past and present state of the aquaculture system

The typical stimulus for starting aquaculture activities is the insufficient supply of wild fish. At the early stage in Vietnam, seed were either trapped from rivers or spawned by small-scale farmers at the household level (Edwards, 2000). Aquaculture activities in Vietnam were promoted during the time of the Vietnam War as a means of improving the food base of the Vietnamese civilians and military (FAO, 2006c). During this time period, the hatchery in Son La as a governmental institution started to supply fish seed to farmers, which has probably been an impetus for further expansion of aquaculture activities in the region. In Son La, the fish production has steadily increased from that time on (Statistic Office Yen Chau, unpublished).

Taking into account that aquaculture production has a long history in Northern Vietnam (Edwards et al., 1996a), the aquaculture activities in the study area seem to be a relatively young activity. About half of the farmers interviewed started digging ponds within the past 20 years for the purpose of fish production. This differs from farmers in the southern Vietnamese Mekong Delta, for example, where bodies of water were initially constructed for other purposes such as establishing orchard dikes and later were used for fish farming (Nhan et al., 2007).

Since new entrant smallholder farmers usually do not have the resources to purchase fertilizers or commercial fish feeds, their obvious starting point is to use any existing on-farm wastes as pond inputs (Prein, 2002). The investigated polyculture ponds comprising mainly omnivorous and herbivorous cyprinid species are well integrated in the overall farming system with manifold on-farm linkages between fish, crop and livestock production. Off-farm resources such as agro-industrial products play important roles in crop production and also, to a certain degree, in animal husbandry. In contrast, farmers operate their aquaculture system by using only on-farm resources (with the exception of fish seed). However, in a very narrow view, manure is not always a real “on-farm” resource, since it is also collected from neighbours and from the road. The same is true for weeds and aquatic plants, which are frequently not collected from one’s own fields.

The bulk of finfish production (over 80%) is carried out in either extensive or semi-intensive pond-based farming systems (compare Tacon and De Silva, 1997). The investigated aquaculture system in Yen Chau, however, has some semi-intensive as well as intensive components according to the classification provided by Edwards et al. (1988; chapter 2.3.3). The overall system can probably be most accurately classified as a “semi-intensive system with lower yields”, even though it also includes non-macrophyte feed resources such as rice bran. Semi-intensive systems are typical components of integrated crop-livestock-fish farming systems (Edwards et al., 1988). Considering only the production of grass carp as the major component of the prevalent aquaculture system, the system is rather intensive. The grass carp receive their major feed inputs through the feed applied (albeit not pelleted feed); the availability of natural food is of minor importance for this fish species. In addition, most ponds have a continuous water flow during the majority of the year; running water is also a typical feature of intensive aquaculture systems. Usually, warm water omnivorous and herbivorous fish species are produced in polyculture within static water pond-based farming systems; compare e.g. Tacon and De Silva (1997).

The current system concentrates predominantly on the production of grass carp. Pond systems with grass carp being the main species have been reported from southern China (De Silva, 2003a). Only one pond system has been described from northern Vietnam, which is similar to the present aquaculture system from Yen Chau. This upland system is characterized by stream-fed flow-through ponds with grass carp accounting for 65% of the stocked species. In this system, stocking densities (2-3 fish m^{-2}), the daily water exchange ($1/4^{th}$ to $1/3^{rd}$) and yields (3 to 5 tons ha^{-1} $year^{-1}$) were reported to be higher compared to those in the presented study (Dien and Quynh, 2001). However, it is not known how this data was collected. Compared to this system, other systems described from northern Vietnam are mainly based on the production of other cyprinids, such as an upland aquaculture system described by Luu (2001b) where only 5-10% of the stocked species are grass carp. In the Red River Delta, for example, carp are raised in polyculture with rohu and silver carp ranking first (Luu et al., 2002).

7.2.2 The yields of the local aquaculture system in comparison with other carp polyculture systems in Vietnam and other Asian countries

The net fish production could not be calculated from the interview surveys alone. Farmers may remember the amounts of fish sold but usually can not provide an overview regarding the remaining fish in the pond. They also have difficulties assessing the household consumption from each individual pond, since they do not catch fish continuously over the entire rearing period. The net fish production in the case study ponds ranged from 1.1 to 1.9 tons ha^{-1} $year^{-1}$, which is relatively low compared to other feed-based aquaculture systems (Edwards et al., 1988).

There is a wide variation between carp yields reported in literature. Fish yields in carp polyculture systems in the Red River Delta range from < 0.1 to 6.7 (average 2.6) tons ha^{-1} per 9-month production season (Luu et al., 2002). In six ponds in northeast Thailand, they range from 0.75 to 4.2 (average 2.2) tons ha^{-1} $year^{-1}$ (Middendorp and Verreth, 1986). De Silva (2003a) reported yields of carp cultures from 5.3 to 14.6 tons ha^{-1} in Andhra Pradesh (India). The average net yields of a typical carp polyculture farm in China were 6.6 and 7.7 tons depending on the species composition and feeding regime (Li, 1987). Also, in an integrated mulberry dike-carp pond system in the Zhujiang Delta in China, annual fish yields reached 7 tons ha^{-1} (Ruddle and Christensen, 1993). In the Red River Delta, yields up to 7.9 tons per production cycle could be achieved with small modifications in the management of stocking and harvesting techniques and improvements in feed supply (Luu et al., 2002).

The high yields from carp polyculture systems that are reported in literature indicate that there is a scope for improvement of the current aquaculture system in the research area. In the following chapter, the individual components of the presented aquaculture system are examined and possible contributors to the relatively low productivity identified.

7.3 Evaluation of the current aquaculture system and possible contributors to the low yields

7.3.1 The water quality in relation to the well-being and growth of fish

Water quality is an essential parameter for effective and disease-free aquaculture systems (Ye, 2001). The quality is influenced by the ambient water and soils, geological and climatic properties of the watershed as well as the pond and farm management practices.

At least for filling ponds and balancing water losses through leaching (seepage) and evaporation, water is required. In the sloping study area, pond water is derived from precipitation and water run-off as well as from springs, irrigation canals or streams. Whereas ground water from (deep) springs is commonly considered to be constant in quality and free of toxic pollutants as well as contamination with predators or parasitic living organisms (Appleford et al., 2003; Summerfelt, 2008), the water quality of watershed ponds is strongly influenced by the land use and household activities. Adverse effects from farm and household activities on the well-being of fish may be associated with the entry of sediments, pesticides and detergents, which will be discussed later (7.3.7). Contamination might be even more severe in ponds located downstream compared to upstream ponds. However, the close linkage between ponds and fields may also have positive external factors, since nutrients from the ponds in the outflow can be reused in the paddy fields. The use of the effluents from a hybrid catfish culture yielded in rice production that was comparable to that which received a regular fertilization regime (Lin and Yi, 2003). The flow of nutrients within the watershed in the Chieng Khoi commune is further investigated within the framework of the "Uplands program".

The presence of water emersion points on the pond bottom is a special feature in some ponds and may be associated with the karst character of the region (2.1.3). These ponds are not completely drainable, which may hamper pond management in such factors as the control of pathogenic agents by drying out the pond floor.

In general, Yen Chau ponds are constructed either consecutively or parallel and water flows by means of gravity. In the case that they are constructed in consecutive order, water flows through each pond before it is discharged. This may lead to water pollution in the ponds located at lower positions, and this layout also has the disadvantage that the decoupling of disease-affected ponds becomes difficult or even impossible. In the case of a parallel pond layout, different ponds receive and discharge water from and to the same canal or stream. Also in this pond layout, ponds at lower locations may be affected by waste-water derived from ponds at higher locations.

Limited water availability for the ponds was a severe problem for a number of fish farmers during the study period, which was very severe at the times of rice transfer. In one of the investigated ponds, for example, the water level dropped from almost 120 cm to only 55 cm (Figure 40). Shallow water has highly fluctuating water temperatures and DO levels.

For ectothermal animals such as fish, the water temperature is critical and influences the growth and well-being of the fish. Usually, the growth of the fish increases with a higher temperature; then, it passes an optimum peak and falls quickly once the temperature approaches the upper lethal limit (Black, 1998). The average temperatures measured over a year ranged between 22 to 24°C in the morning and 23 to 26°C in the afternoon. The lowest water temperature sampled was 13°C and the highest was 33°C over the entire course of the study period. Grass carp can tolerate a wide range of temperatures from 0 to 38°C (Fishbase, 2006b). The preferred temperature is around 29°C, and the superior incipient lethal temperature is 39.5°C (Alcaraz et al., 1993). The ideal temperature range for fish culture is generally above 25°C for most warm-water Asian fish (Cagauan, 2001) and feeding activity tends to decrease or stop at temperatures below 20°C (Ling, 1977).

Whereas the water temperatures in the study area were close to the optimum during the hot summer months, they probably did not satisfactorily support fish growth in the wintertime. The relatively cold winters in the study area limit fish production and may even lead to mortalities of the tropical fish species such as pirapitinga and tilapia.

While tilapia can tolerate high temperatures, up to 42°C in the case of *O. niloticus* (Fryer and Iles, 1972), at temperatures below 20°C they generally reduce feeding and other activity, which stops completely at temperatures around 16°C (Chervinski, 1982). It has been reported that tilapia begin to die when the water temperature drops to 11°C (Sifa et al., 2002) or 13.6°C (Charo-Karisa et al., 2005). The relatively cold winter in the study region is therefore not suitable for the year-round production of tilapia on a large scale. The lowest water temperature measured was 13.4°C (6.2.1). However, it is likely that the temperatures dropped even lower than this, since the measurements usually took place after sunrise and the temperature was not monitored permanently over the entire study period. The observed tilapia mortalities are further indices of this.

Another factor associated with temperature that probably led to stressed fish and even fish mortalities in the study area are temperature shocks. This occurs when fish are transferred to a new pond without first letting them adapt to the new environment. Furthermore, heavy rainfalls and/or hailstorms can also lead to sudden temperature changes. Temperature changes (e.g. water colder by 8°C) that occur shortly after feed application may stop or slow down the digestive processes with the result that food remains undigested or half-digested in the digestive tract. This may lead to gassy and bloated fish, which could lose their balance and die (Svobodova et al., 1993). However, while some temperature-related mortalities may be avoided through better management such as a proper tempering of fish, not much can subtend the mortalities in the case of sudden environmental changes. However, if farmers avoid feeding fish when heavy rains are announced, it may at least mitigate the adverse effects on the fish.

The sudden fish deaths that occur after heavy rainfall may also be related to high (oxygen requiring) organic loads on the pond bottom. Especially after some days of windless cloudy weather and a consequently low DO availability caused by the low photosynthetic activity of aquatic plants, sudden rains may lead to a depletion of the available DO. When the surface temperature is lowered as a result of the rain, warm water from the bottom rises and the pond bottom may be turned upside down within only a few hours (Ling, 1977). After a hailstorm in April 2006, for example, the DO level was recorded to be near zero and the SDD below 10 cm in two of the case study ponds (Table 23).

As the temperature increases, the DO content of the water decreases; however, the DO requirements of the fish increase. Oxygen is the first limiting variable in the aquatic environment; the food intake of fish may be suppressed with limited oxygen supply (e.g. Black, 1998; Ross, 2000). Absolute lethal limits are species-specific, e.g. < 0.5 mg l^{-1} in the case of grass carp (Fishbase, 2006b). Tilapia is a representative for fish tolerant to low DO concentrations and may survive short-term exposures to 0.1 mg l^{-1} DO. Nevertheless, tilapia will not tolerate low DO in the long-term, nor will they grow, feed, digest or reproduce in a typical way under these conditions (see Ross, 2000).

In general, DO levels above 5 mg l^{-1} are usually recommended for warm-water aquaculture (review of Boyd, 1982; Cagauan, 2001; Summerfelt, 2008). The average DO levels at 8 a.m. were typically between 2 and 4 mg l^{-1} in the case study ponds. Much lower DO concentrations occurred at dawn, which was indicated by fish gasping for air at the pond surface. Hypoxic events usually occur in the morning after high oxygen consumption by aquatic organisms in the night (e.g. Black, 1998). In the example of SV1 in Figure 35, the DO levels at dawn were close to zero. The chronic exposure to lower oxygen concentrations may have adverse effects on feeding and growth and may lead to a higher susceptibility to diseases among stressed fish (Summerfelt, 2008).

Oxygen comes from the photosynthesis of aquatic plants, mixing of air with water as well as from the inflowing water. The more or less frequent water-flow is a particular feature of the ponds in the study area. In intensive farms, a high water exchange is required in order to wash out the excretory products from the fish and to maintain an adequate DO level (Appleford et al., 2003). In the case study ponds, the amounts of water flowing through the ponds varied enormously among the measurements and the average water exchange rate was much lower compared to intensive trout farms with hourly or twice-hourly water exchanges, for example (Scheffer and Marriage, 1975).

The inflowing water carried DO into the system, although only relatively low amounts due to the low amounts of water. In the case of very low oxygen availability in the ponds, the inflow might mitigate the problem of DO insufficiency, especially in the vicinity of the water inlets. However, the water flow does not result in overall DO levels in the ponds considered suitable for fish culture.

In ponds with higher water flow, there tended to be a lower presence of plankton availability, which is discussed later in this book (7.3.4). Furthermore, the sediments entering the pond with the water flow regularly led to turbid water in the hot and rainy season. Also, some of the stocked fish species tend to burrow in pond mud in search for food, which may also contribute to the sediment-caused turbidity. Water is considered turbid with a SDD lower than 30 cm (Sevilleja et al., 2001). The turbidity limits photosynthesis due to impaired sunlight penetration and thereby reduces the production of DO.

Pond SV1 demonstrated the highest amplitude of DO between the morning and afternoon measurements as well as the highest phytoplankton concentration (e.g. of Chlorophyceae) among the case study ponds. The high fluctuations of DO can probably be related to relatively high photosynthetic activity during the day and a relatively high consumption of DO by these organisms at night. In the respective pond, the water source was almost free of sediments, since the water originated from a spring nearby and was not polluted from erosion.

Oxygen is consumed through respiration, decomposition and mineralization of organic material and lost to the atmosphere as well as with the water outflow. In the study area, the oxygen-requiring microbial degradation of the feed leftovers on the pond bottom is assumed to have a major impact on the low DO availability. Farmers tended to apply huge amounts of slowly degrading (fibre-rich) plant material, which is discussed in chapter 7.3.5.

Whereas the temperature and DO levels are often not suitable for fish culture, the slightly alkaline pH is considered to be favourable (Svobodova et al., 1993). In contrast, pH values above 10.8 and below 5.0 may be dangerous for cyprinids (Svobodova et al., 1993), values that are very much different to those values measured in the case study ponds.

7.3.2 Fish characteristics, stocking practice and fish quality

In general, cultured species in the case study farms correlate with species typically produced in the region with the exception of a few catfish raised in farm SV1 and pirapitinga in two farms that were not considered in the study on the micro level. Pirapitinga are omnivorous fish that belong to the subfamily Serrasalminae; they originate from the Amazonian basin (FAO, 2006d) and are produced in ponds in China (FAO, 2006d) as well as Vietnam (Leschen, 2003; Vietnam News, 2003). These fish adapt well to any tropical environment, but in the case that they are starving, they are known to attack other living fish (see Vietnam News, 2003) and cause serious bites with their powerful dentition (Robins et al. quoted in Fishbase, 2006c). Similarly, parts of small fish were recovered from the intestines of the pirapitinga caught in the case study ponds. It is likely that the low survival rate of fish in the nursery pond of SV3 (chapter 6.3.1) was partly caused by the presence of this fish species. Farmers stocked this "exotic breed" without being aware of these typical properties or considering an adequate combination of fish with suitable sizes in order to avoid fish killing.

The stocking of different fish species was usually based on the farmers' preferences and experience as well as the availability and prices of the individual species rather than the creation of an ideal fish combination. It appeared that farmers were usually not aware of the feed base of the individual fish (typically with the exception of the grass carp). However, an adequate combination of fish species at appropriate densities is required to fully exploit the advantages of a polyculture system (e.g. Milstein, 1992). The combination of species in the case study ponds is discussed in more detail in chapter 7.3.4.

In the interviews (meso level), farmers reported stocking 1.6 fish m^{-2} on average, but nothing is known about the real stocking densities in these ponds. In the case study ponds, the average stocking density was only 1 fish m^{-2} with considerable differences among the ponds, ranging from 0.4 to 1.8 fish m^{-2}. Also, stocking densities in IAA systems in different regions of the Red River Delta varied enormously and ranged from 0.04 to 14 fish m^{-2}, which correlated significantly with fish yields (Luu et al., 2002). Here, the average stocking density was 2.2 fish m^{-2}; thus, it was more than double the amount of the fish stocked in the case study ponds. Also in the case study ponds, higher yields tend to correspond with higher masses stocked; however, there was no clear correlation between those parameters.

Fish densities have to be adapted to the individual pond conditions in order to find the "optimal stocking densities", which results in a production that is highest in the quantity and quality of fish and is most profitable (Kumar, 1992). Higher stocking densities typically result in higher total production, but at stocking densities above the optimum, fish compete for food, space, dissolved oxygen and are stressed due to aggressive interaction. These factors may all result in decreased fish growth and a higher susceptibility to infection. Normally, the proper density of fish is directly related to the abundance of food (Little and Muir, 1987), which is discussed in the following chapters.

The amount of fish stocked was, to some extent, a result of farmers' liquidity during the major stocking procedure, e.g. farmers of SV1 had a higher income in the year 2004 compared to the other farmers, which allowed these farmers to purchase more (and partly larger) fish for stocking. Similarly, some of the interviewed farmers reported that they could not buy additional fish because of their lack of money. Also, Martinez Cordero et al. (1999) reported that suboptimal stocking densities were related to farmers' limited financial resources in Sulawesi.

Besides the financial aspects, the general seed availability in the local hatcheries also influenced the stocking densities. An instable seed supply is also known to be the case in other areas (Edwards, 2000). Appleford et al. (2003) stated that a reliable source of fish seed in adequate quality and quantity is fundamental to all aquaculture ventures.

When comparing advances achieved in breeding technology in aquaculture with terrestrial animals, relatively speaking, aquaculture is still in its infancy (Delgado et al., 2003). Chinese carps, such as grass carp, are highly fecund river spawners and do not breed naturally in ponds (Rottmann and Shireman, 1992; Beveridge and Haylor, 1998); thus, they need to be produced in hatcheries. The local hatchery operators as well as farmers observed a decrease in the quality of fish seed over the last several decades. Factors that are associated with the decreasing quality are a low growth performance of fish as well as the susceptibility of grass carp to diseases. There is some evidence that the inappropriate management in the local hatcheries (e.g. crossing of fish without considering the degrees of relationship) as well as use of a restricted gene pool led to a genetic degeneration of local fish. Now, the hatchery operators are seeking funds in order to improve their genetic resources.

Genetic degeneration of carp has also been observed in neighbouring China. Ye (2001) stated that most of the brooders of the main cultivated fish in China are derived from wild strains, that little mass selection is applied and that almost no genetically improved strains have been obtained so far. Inbreeding and unsuitable genetic manipulation led to the appearance of genetic degeneration, such as slower growth, poor resistance to disease and earlier maturation.

The quality of the young fish may also be influenced by suboptimal feeding in the hatcheries. After the yolk sac of grass carp larvae has been depleted (1-3 days), larvae start feeding on exogenous food (Rottmann and Shireman, 1992). As in the early developmental stages of almost all fish, the larvae and fry of grass carp feed on small invertebrates, which primarily consist of zooplankton (see 2.3.2). In order to improve the availability of zooplankton, ponds require certain amounts of manure. In rather intensive fry rearing, live food (e.g. freshwater rotifers and brine shrimp (Artemia)) is cultured separately and then fed to the fry (Rottmann and Shireman, 1992; Southgate, 2002).

In the Son La hatchery, however, the first feed given to the larvae following the consumption of the yolk sac is the ground yolk of duck eggs. The feeding of suspended material to fry is usually associated with a number of unwanted effects: the material is not buoyant; thus, the availability of food to the (not yet free swimming) larvae is reduced, the food particles may settle on the tank bottom and pollute the water quality as well as increase bacterial activity (Southgate, 2002). After two days of feeding, fry are transferred to ponds and supplied with germinated rice, soybean and grass and leaf material as well as small amounts of manure. It is questionable whether the applied grass and leaf material functions as fry feed. Grass carp change their feeding habits and exhibit herbivorous tendency at a larger body size (see 2.3.2). However, the applied green material probably acts as a substrate for zooplankton production in the ponds. Hay, for example, has the advantage of encouraging the long-term production of zooplankton (Rottmann and Shireman, 1992). The practice of supplementing natural food with applied feed has been recommended when fry are stocked at high densities (Rottmann and Shireman, 1992). The feeding of egg yolk paste or soybean milk and peanut cake to grass carp and bighead carp up to the age of 30 days has also been reported from China (Jhingran and Pullin quoted in De Silva, 2003a).

The stocking of low quality fish probably influences the whole fish production in farmers' ponds and might negate farmers' efforts through better pond management. However, farmers do not only obtain fish from the local hatcheries, lowland fish suppliers also deliver fish seed to the region. In addition, tilapia and common carp reproduce naturally in farmers' ponds and therefore do not need to be purchased on a regular basis.

The early and uncontrolled reproduction of Nile tilapia may lead to overpopulation in ponds. Normally, this is accompanied by competition for space and food resources among the offspring and a considerable quantum of the energy intake is utilized for reproduction purposes and not for growth. The result of this is "stunting", where there is a large number of fish of limited size (Suresh, 2003). This was also observed in the case study ponds, where a large number of tilapia with body sizes rarely exceeding 50 g were caught and the small fish then fetch comparatively low fish prices. One method for controlling the reproduction of tilapia is the use of synthetic testosterone to produce sex-reversed, (phenotypic) all-male tilapia, a technique that is used by the Son La hatchery and which may be associated with a number of environmental effects as well as health concerns (see review of Pandian and Sheela, 1995). It is surprising, since all tilapia sold from the main fish supplier in the region are supposed to be males, that the tilapia reproduction in farmers' ponds is still obviously high. However, the effectiveness of hormone treatment is quite variable and depends on various factors, which makes it difficult to achieve the desired 100% male stock. However, even a small proportion of females may result in significant levels of recruitment (Mair and Little, 1991).

The above-mentioned factors, including the low quality of fish seed, the instable access to stocking resources and the stocking densities that are potentially too low, might have contributed to the relatively low yields in the study area. Veerina et al. (1999) found that besides the stocking density, the application of protein and organic fertilizer also has a large impact on carp yields in Andhra Pradesh (India).

7.3.3 Rating the growth of grass carp and the quantity and quality of the applied feed

The herbivorous grass carp make up the major species in the current system, which is a result of its relatively rapid growth potential, its ease of marketability at comparatively high prices as well as its ability to use the available on-farm crop residues as major feed inputs. The feeds currently used in the research area consist mainly of plants, either terrestrial or aquatic, that come from the wild or from cultivated crops. Most of the feed inputs cannot be used directly by humans in this form; however, through their application in the ponds, they can be converted into high-value animal protein.

The grass carp is believed to be the major species that feeds on the applied green fodder, which accounts for an average of 80% of the applied feed material (FM) in the case study farms. This is based on observations of the grass carp feeding behaviour and was confirmed by the examination of the intestine contents. Spataru et al. (1983) also found mainly plant remains in the intestines of grass carp; only 2% of the intestinal content was made up detritus and zooplankton. To a lesser extent, other fish species in the system may have also profited directly from this kind of diet. During the study, plant material was found in the intestines of tilapia, common carp and pirapitinga, which matches their feeding habits as reported in literature (FAO, 2006b; for pirapitinga: Fishbase, 2006c). Also, silver barb are known to feed on plant material (Fishbase, 2006a), which was also observed during the study period. No plant material was found in the intestines of two silver barb caught from the case study ponds. However, the number of dissected fish was too low to come to definite conclusions.

Although the applied fodder was mainly consumed by grass carp, the growth rates of this species were low compared to the growth rates reported in literature. The average SGR of grass carp from the case study ponds was 0.24% and therefore much lower than most SGR reported from grass carp that were fed terrestrial and aquatic plants in feeding experiments (see Table 3). With the exception of the publication from Tan (1970), all of the studies were carried out in aquaria or tanks and, thus, under different conditions as the grass carp in the research area. When grass carp with a body weight of approximately 300 g were fed in ponds, the SGR (calculated based on the data provided) was 1.06%, when fed solely *Hydrilla*, 1% when fed Napier grass and 0.49% when fed cassava leaves (Tan, 1970). The SGR (calculated based on data provided) was approximately 0.35% in grass carp grown naturally in a lake in Florida (Shireman et al., 1980). Sinha and Gupta (1975) reported a tremendous growth of grass carp when these fish were raised in polyculture and stocked at a low density. Here, grass carp grew from 31 g to more than 2.5 kg within a 6-month period (SGR: ~ 2.41%).

The growth of the individual grass carp in the case study ponds may be related to the grass carp densities that were stocked as well as the overall size of the ponds. The highest grass carp growth rates (as well as condition factors) were observed in the ponds CK2 and VL2 (Table 34). Here, grass carp were stocked at a lower density (based on biomass) compared to the densities in the other ponds. Furthermore, these two ponds were larger than the other ponds. It was previously reported that a lower stocking density may yield larger individual fish (Kumar, 1992). In addition, a “living space effect” may come into play here, which means that grass carp will grow bigger in larger ponds compared to small ponds even under identical conditions including identical management levels and stocking densities (Prowse, 1971).

In the study area, it is widely practised by farmers to stock grass carp with a body weight of 300 g or more. Farmers argue that big fish grow faster than small fish. However, this can not be supported by the growth rates reported in literature, where the SGR was usually higher for smaller rather than larger fish (Shireman et al., 1978; Hajra, 1985). Also, in the case study ponds, the highest grass carp SGR was reported from farms CK2 and VL2, where fish had the lowest initial weights. However, a body weight gain of 100% in the case of small fish (e.g. from 20 to 40 g) is not as impressive as in an increase of only 50% in the case of big fish (e.g. from 1.0 to 1.5 kg). This observation may have led to the farmers’ conclusion.

Despite fish density, pond size and fish weights, growth rates also depend on the growing season, quality and nutritional value of the feed as well as the feed amounts applied to fish. The body weight gain, SGR, feed and protein efficiency were significantly affected by the feeding rate of juvenile grass carp that were raised in tanks (Du et al., 2006).

The typical feed items applied to ponds did not differ between the case study farms nor were differences reflected in the information gathered on the meso level. However, in the latter survey, no reliable data regarding feeding amounts could be gathered. The daily feed application in the six case study ponds was 15.4 kg FM per pond and includes all types of feed items. The feed application was highest in case study farm CK1, which was not reflected in the fish yields of this pond. Yen and Binh (2005) reported that farmers from Tuyen Quang province (Northern Vietnam) typically cut 30-40 kg of fresh plant material to feed their fish in an 800 m^2 pond. In this region, the typical composition of fish feed is similar to the feed applied in Yen Chau district. It is not known which method was applied to estimate these amounts. In the Red River Delta, farmers followed recommendation from the extension services and applied 61 tons ha^{-1} grass, 24.7 tons ha^{-1} pig manure and 5.4 tons ha^{-1} rice bran to their ponds, which resulted in an annual fish production of almost 5 tons ha^{-1} (Luu et al., 2002). In contrast to the amounts of manure, only slightly lower amounts of green plant material as well as other feed items (partly comprising rice bran) were applied to the case study ponds.

However, all of this data is based on fresh material, which makes it difficult to compare since the applied feed items usually vary in their moisture contents (e.g. duckweed versus grasses). The application rate, however, depended on a variety of factors; besides the fish weights and the season (lower feed application in winter), the current farm activities and labour availability also played a role.

The feed is mainly distributed among ruminants and fish. Farmers highly value large ruminants, such as buffalos (e.g. draught, social status), and they are usually given priority. However, the number of ruminants per household is rather low and the scope for increasing this number is limited (stable requirements, investment costs, etc.); therefore, farmers will normally still have feed leftovers that they can apply to their fishponds. Beside short-term bottlenecks in the wintertime, abundant crop leftovers were available for the fishponds at the case study farms.

Grass carp have to consume large quantities of plant material in order to obtain the required amounts of nutrients (Tan, 1970; Cui et al., 1992, 1994). This differs for carnivorous fish, for example, which consume comparatively low quantities of nutrient-dense and highly digestible foods. The gross relationship in the case study ponds between the green fodder application (FM) and the net gain of grass carp biomass (FM) showed that 1 kg of grass carp is produced when approximately 68 kg (11.8 kg DM) of grass and leaf material are applied to the pond. This figure is similar to the statement made by Sinha (1985), who reported that roughly 60-70 kg of grass and vegetable tops are required to produce 1 kg of grass carp.

In the present study, the FCR varied enormously between the ponds; between 4.5 to 20.2 kg of dried plant material was required to produce one kg of grass carp. The data presented in literature reflects the same findings; the FCR of grass carp fed different plant diets (calculated on DM basis) also varied greatly. Only 2 kg of the dried aquatic plant *Spirodela polyrhiza* and up to 24 kg of ryegrass pellets were required to produce one kg of grass carp weight; see Table 3. However, it is difficult to compare this data since those experiments were carried out with grass carp that were raised as individuals under controlled laboratory conditions and were exclusively fed one diet. In contrast, the grass carp in the study area were raised in ponds and subjected to changing environmental conditions. In addition, the other fish in the polyculture system might have also consumed a portion of the diverse feeds that were applied to the ponds. This may be assumed in the cases of CK1 and SV1, for example. Both of these ponds presented the largest amount of herbivorous silver barb, which probably consumed a portion of the plants applied to the ponds and therefore led to the comparatively high FCR in those ponds.

The composition of the analysed feeds (Table 29) is in the range of those described for different varieties and products of cassava (see review of Göhl, 1981; Charles et al., 2005; Hang and Preston, 2005), leaves and meal of maize (see Göhl, 1981; Southgate, 2002), bamboo (see Göhl, 1981), sweet potato (see Göhl, 1981) as well as Napier (Venkatesh and Shetty, 1978a) and barnyard grass (see Göhl, 1981). The content of crude protein in the mulberry and banana leaves, however, was considerably higher in the varieties collected from the study area compared to the varieties summarized by Göhl (1981).

The general quality of the applied feeds can be considered to be rather poor, since they have high moisture and fibre and relatively low protein content. Certain feeds, however, contained considerably high contents of crude protein and gross energy, which was the case with cassava and mulberry leaves. However, high protein content does not necessarily indicate a better quality diet, which has been demonstrated by authors such as Shireman et al. (1978) and Tan (1970). Low fibre content is also an important criterion. Digestibility coefficients of crude protein and gross energy, for example, declined significantly with increased fibre content in the plant feed (Hajra et al., 1987). Besides the gross-chemical composition, the presence of antinutrients may also influence fish growth (Francis et al., 2001a,b; 2002). The applied banana leaves, for example, contained tannins and saponins, and the cassava leaves contained cyanides, tannins and haemolytic active saponins (Dongmeza et al., 2009a).

Despite the worldwide importance of cyprinids, little is known about their dietary nutritional requirements compared to carnivorous species (Tacon and De Silva, 1997). A possible reason written by the authors might be the fact that the majority of carnivorous finfish production as well as aquaculture/nutrition research takes place in “developed countries”, while the bulk of the production and research regarding omnivorous/herbivorous species is carried out in “developing countries”.

So far, with the exception of a few items (e.g. duckweed), little information has been published regarding the types of feeds used as grass carp nourishment in the study area. In connection with the presented research, an aquaria system was set up at Hanoi University of Agriculture (HUA) that was made up of 15 aquaria connected to a recirculating system with mechanical and biological filtration. Here, it was intended to study the growth rates of grass carp fed on the diverse feeds under controlled conditions. Unfortunately, due to instable access to water and power supply in the aquaria system, only one feeding trial could be completed during the research phase in Vietnam, which has been partly published by Tuan et al. (2007). During the investigations in Vietnam, feeding trials were carried out in aquaria and respirometry systems at the University of Hohenheim (UHOH). In these experiments, grass carp were either fed a standard diet (control group) or the standard diet supplemented with dried cassava leaves or weed mixtures (Dongmeza et al., 2009b), leaves from banana or bamboo (Dongmeza et al., 2009c), or leaves of maize or barnyard grass (Dongmeza et al., 2009d). The leaves and weeds used, with the exception of the maize leaves, came from the farmers in Yen Chau.

Even though cassava contains toxic compounds, it is widely incorporated in livestock diets with satisfactory results (Göhl, 1981; Ng and Wee, 1989). In the trials at UHOH, Dongmeza et al. (2009b) investigated growth and food conversion of grass carp supplemented with dried cassava leaves over a 12-week period. Even though these fish received leaves in addition to the same amount of standard diet as the control group and, thus, a larger amount of nutrients, the growth as well as the feed utilization was generally lower in the cassava-supplemented fish. While both groups showed similar growth in the first eight weeks, the growth of the cassava-supplemented fish lagged behind afterwards. The authors attributed the growth depression to the intake of antinutrients. When grass carp were fed solely on cassava leaves in ponds, a growth depression was observed after a 6-week feeding period (Tan, 1970). An increase in cassava leaf meal in the form of pellet feed led to an almost linear depression of growth performance as well as food and protein utilization in Nile tilapia (Ng and Wee, 1989). In this study, however, the poor growth performance was attributed to poor digestibility and low dietary energy content rather than to the ingestion of cyanides.

In the study area, farmers of CK1, for example, applied huge amounts of cassava leaves to their pond, accounting for almost 30% (excluding the uneaten petioles) of the total applied DM from feed and manure. The long-term use of large amounts of cyanide-containing cassava leaves might have been responsible for the comparatively low specific growth rates of these grass carp. This action as well as the possible impact of cyanides on the health of fish in the study area will be discussed later in this book (7.3.7).

In the experiment carried out by Dongmeza et al. (2009c), grass carp that were supplemented with banana leaves had a significantly higher body weight gain compared to the control group fed the same amount of standard feed only. In the feeding trial carried out at HUA, grass carp fingerlings (~ 20 g) were either fed banana leaves, barnyard grass or Napier grass for an 8-week period. In contrast to the Napier and barnyard grass-fed groups, there were no mortalities observed in fish fed on banana leaves only. Also, the body weight gain was higher in this group (88.6±39.8%), whereas the body weight gain of those fish that survived in the barnyard and Napier grass-fed groups was only 36.0±36.4% and 26.4±22.6%, respectively. Among the banana leaf-fed fish, the SGR was 1.0±0.3% and the FCR 5.5±1.0.

Barnyard grass is an important weed in paddy fields (Kangmin, 1988; Biotrop, 1993; IRRI, 2006) and plays a major role in rice production in Vietnam (Chin, 2001). This grass is not a reliable forage plant and has no economic importance for grazing (Duke, 1983). In the feeding trials carried out at UHOH, Dongmeza et al. (2009b,d) observed lower growth rates in grass carp supplemented with either barnyard grass or mixed weeds from the paddy fields compared to the respective control groups. Barnyard grass, as well as the mixed weeds used in the study area, tended to have a lower protein and fat content as well as a higher fibre content compared to the applied leaves from cultivated crops. This is supported by the findings of Tan (1970), who analysed some of the grasses and leaves used as fish feed in Malaysia. The high mortalities and slow growth rates of grass carp observed in the feeding trial carried out at HUA indicated that barnyard grass as well as Napier grass are probably not able to effectively support the growth of young fish when they are fed this alone. In contrast, Tan (1970) and Venkatesh and Shetty (1978b) reported respectable growth rates from grass carp that were fed Napier grass only. However, in the experiment carried out by Tan (1970), the initial size of fish was larger compared to the fish used at HUA, and it has been reported that large fish are able to better utilize Napier grass compared to small fish (Venkatesh and Shetty, 1978b). The same has been found in the case of feeding ryegrass pellets only, where small fish exhibited lower survival rates and more abnormalities compared to larger fish (Shireman et al., 1978). Opuszynski (1972) stated that fish fry is not developed enough to consume solely plant food; thus, they require supplementary animal protein for better growth. In general, the conversion of plants increases with the growth of grass carp (Opuszynski, 1972).

The experiments presented by Dongmeza et al. (2009b,c,d) were carried out with dried material. There is possibly a difference between the use of fresh and dried leaves and grasses. In the feeding trial carried out with maize leaves, Dongmeza et al. (2009d) compared fish supplemented with fresh and dried maize leaves. In the aquaria, the fish that were fed fresh maize leaves had a significantly higher body weight gain compared to the control group and the group supplemented with dry maize leaves. However, Law (1986) stated that grass carp are able to digest fresh grass and dry grass meal in the same way and recommended the use of dried plant materials in the form of pellet feeds for grass carp.

Compared to the above-listed terrestrial plants, quite a number of reports have been published concerning the growth of grass carp fed on aquatic plants (see chapter 2.3.2). There is some evidence, however, that aquatic weeds are better digested compared to terrestrial plants (Tan, 1970). Also, farmers in the research area fed considerable amounts of a mixture of duckweed (*Lemna* ssp.) and azolla.

The availability of little or no indigestible material makes duckweed a feed opportunity for monogastric animals (Leng et al. 1995) and can be efficiently converted to live weight of certain fish species, such as carp (Cui et al., 1994; Azim and Wahab, 2003), Thai silver barb (Azim and Wahab, 2003) as well as tilapia (Gaigher et al., 1984; Hassan and Edwards, 1992). However, the relative growth rate was poor (0.67% body mass day^{-1}) when tilapia (*Oreochromis niloticus x O. aureus*) were fed *Lemna gibba* alone (Gaigher et al., 1984). Also, in the case of grass carp, not all authors reported satisfying growth rates. The SGR ranged from 0.24% to 3.88% and the FCR from 1.6 to 3.2 in the examples presented in Table 3. Azolla is an aquatic floating fern, which is characterized by its ability of fixing atmospheric N through the cyanobacterium *Anabaena azollae* (Ayyapan, 2001b) and its consequently high N-content (Watanabe, 2005). For this reason, azolla has been traditionally used for centuries as green manure in some parts of China as well as for wetland rice in Northern Vietnam (Watanabe, 2005). Nutritional values of duckweed (Leng et al, 1995) and azolla (Watanabe, 2005) vary greatly among species.

While some of the feeds applied most likely do not contribute significantly to the growth of fish in the research area, such as bamboo leaves, cassava leaves, barnyard grass and mixed weeds, some of the feeds appear to exhibit good potential as supplementary feeds, such as banana leaves, fresh maize leaves as well as the mixture with duckweed. There was, however, no correlation in the proportion of the above-listed “good” and “bad” feeds applied and the grass carp growth rates in the case study ponds.

Farmers define Siam weed as being a “green manure” for their pond. Fish do not eat it immediately after its application, but 2 or 3 days after its application to the water. Siam weed is considered to be one of the world’s most invasive weeds and is found in many tropical and subtropical regions of different continents (e.g. Ye et al., 2004; Queensland government, 2007). It has been reported that livestock usually avoid eating the bitter leaves and that its consumption can even cause the death of cattle (Queensland government, 2007). In the current study, leaves were analysed before and after a three-day application to the water; however, only a small difference (< 2%) was found regarding its N-content. Therefore, a direct fertilizing effect in the form of N is quite doubtful. It might be the case that the above-mentioned bitter substances in the Siam weed leaves disperse into the water, which makes the leaves more palatable for fish. A reduction in the offensive odour of fresh leaves is greatly reduced after sun-drying the leaves (Fasuyi et al., 2005). Also, microorganisms that flourish on the leaf material might also attract the fish. However, the fact that the feed is consumed after a couple of days makes the Siam weed a direct feed rather than a "manure".

The differentiation between "green manure" and "feed" is not always clear in the literature, especially when grass-eating fish are stocked. Shan et al. (1985), for example, named the grasses and aquatic plants applied to their pond "green manure" even though it was directly consumed by the herbivorous species stocked. The plant material may decompose and provide nutrients to the pond. Alternatively, the grass carp may process the raw plant material and supply their poorly digested excreta to the pond, which then serves either as fertilizer or may be directly consumed by the other species in a polyculture system (Prein, 2002).

7.3.4 Rating of the growth of the non-grass carp species and their availability of feed

Unfortunately, the growth rates of the other fish species (the non-grass carp species) could not be satisfactorily estimated in the current study because of the afore-mentioned reasons. Not all of the growth rates could be concluded; however, the small amount of data gathered indicates that the growth rates of the non-grass carp species were also much lower compared to the diverse growth rates reported in literature. The SGR of most of the fish in the case study ponds did not exceed 0.5%; only the silver barb exhibited a maximum SGR of 0.73%. In contrast, the SGR (calculated on the basis of the data provided) of silver carp and mrigal in a polyculture of six different species were 1.16% and 1.83% respectively (Sinha and Gupta, 1975). The SGR of silver barb and common carp grown together with rohu and catla in duckweed supplied ponds were 3.10% and 2.93%, respectively (Azim and Wahab, 2003). For either bighead carp or silver carp grown with grass carp, common carp and tilapia, the proximate SGR were 1.26% for silver and 1.6% for bighead carp (Spataru et al., 1983). The SGR of silver barb grown in rice fields varied from 0.27% to 3.6% body weight per day (Vromant et al., 2002a).

While the feed items that have been discussed so far are most likely almost exclusively eaten by herbivorous fish, the by-products of cassava, maize and rice (other than the leaves) are thought to play a major role as supplementary feeds for the other fish species in the present system. In addition, most of these species are also known to feed on the natural food available in the ponds (see Table 2). As mentioned before, it is not possible to clearly divide the feed into categories according to the feed for the grass carp and for the non-grass carp species. It has been reported that grass carp also feed on rice bran (Law, 1986) as well as the green algae *Spirogyra* sp. (Stanley and Jones, 1976); however, the grass carp did no grow well on these items.

In the case study ponds, quantitatively, the most important supplementary feeds were rice bran and cassava peel. The rice bran was usually of low quality and partly comprised rice hulls, which may explain the low crude protein content found in the rice bran in the study area (7.7% of DM) compared to the protein content of rice bran reported by other authors (10.6-13.7% of DM; see Göhl, 1981 and Southgate, 2002); this may also explain its comparatively high fibre content. Rice bran is fairly palatable to most farm animals (Göhl, 1981) and has been incorporated into the diets of carp (FAO, 2006b) as well as tilapia (Suresh, 2003). As a primary or exclusive feed, however, it is considered to be nutritionally imbalanced (Edwards et al., 1996b). Since rice bran is a relatively costly input and is also fed to the other farm animals, its use is generally limited. The peel from cassava tubers was found to be low in protein and fat, similar to other reports (see Göhl, 1981), and contained considerable amounts of fibre and lignin. It could probably be considered a poor feed for fish, since it additionally contains considerable amounts of cyanides (Dongmeza et al., 2009a). Tilapia, common carp, mud carp and mrigal are known to make use of agricultural by-products (FAO, 2006b). However, the low quality of the rice bran provided as well as the low nutritional value of cassava peel, both being quantitatively the most important food inputs besides leaves, grasses and manure, have probably not contributed significantly to the growth of these fish species.

In the study area, the availability of livestock manure for pond use is limited by a shortage of livestock and the competition with other users such as paddy rice. Also, the collection of animal droppings is often hindered by the scavenging of certain animals like poultry.

The source of the manure applied to ponds typically varies. Pond CK1, for example, was supplied with 233 kg year^{-1} of buffalo manure (DM), which corresponds to approximately one-third of the amount of manure produced by one buffalo in the same period of time (Müller, 1980). Since no buffalos were reared on this farm, all of the manure was collected from public places.

It has been observed at the pond site that fish (particularly tilapia) fed directly on floating manure particles. Manure can be utilized either by direct consumption of feed remnants, as stimulation for natural food production in the pond (e.g. Ling, 1977; Wohlfarth and Schroeder, 1979; Wohlfarth and Hulata, 1987), as a substrate for bacterial production (detritus) and as zooplankton feed (Sevilleja et al., 2001). In general, the feed value of manure as direct feed is considered to be low, which has been explained by its low content of metabolic energy and protein in comparison to conventional feedstuffs (Wohlfarth and Schroeder, 1979). The buffalo manure applied in the study area had a much lower CP and GE content compared to the majority of feed items applied by farmers, pointing at its low value as feed. The micro-organisms flourishing on the manure rather than the manure particles themselves might have attracted the observed tilapia. It has been previously reported that Nile tilapia may utilize bacteria as a feed source (FAO, 2006b).

Manure from buffalo was by far the most common applied manure in the six case study ponds considered and accounted for an average of 94% of the total applied amounts. The DM (19.2% of FM) and N-content (1.4% of DM) of the buffalo manure used in the case study pond corresponds to those reported from Edwards et al. (1994a, b; 1996b). Due to the low N-content of buffalo manure, it is necessary to apply high quantities to the pond in order to reach the recommended N-rate of 4 kg N ha^{-1} day^{-1} (Edwards et al., 1994a, 1996b). The daily loading rates of 100 to 300 kg DM ha^{-1} day^{-1} yielded in the extrapolated net production of 2.4 to 3.7 tons ha^{-1} $year^{-1}$ of Nile tilapia under on-station conditions (Edwards et al., 1994a) and tilapia net yields of 1.8 tons ha^{-1} $year^{-1}$ were obtained with a manuring rate of 200 kg DM ha^{-1} day^{-1} in field trials in Northeast Thailand (Edwards et al., 1994b). Although Edwards et al. (1994a) showed a significant positive relationship between the rate of buffalo manure application and fish growth, they concluded that the conversion of manure is rather inefficient. For instance, the conversion of manure (DM) to fish (FM) was only 13-25:1 in the on-station experiment (Edwards et al., 1994a) and 34:1 in the field experiment (Edwards et al., 1994b). According to calculations, a Thai farmer has to collect 4 tons of fresh manure over a period of 7 months for his 200 m^2 pond in order to harvest only 20.7 kg of fish (Edwards et al., 1994b). This is of particular concern considering the limited availability of labour, which is the case in the study area.

The high rates of manure application resulted in stained water which contributed to a low phytoplankton biomass (generally <15 mg l^{-1}) due to limited light penetration as well as to DO levels at dawn, which were close to zero (Edwards et al., 1994a; Shevgoor et al., 1994). Also, the buffalo manure applied in the study area might have contributed to the turbid-brownish water colour and low DO levels observed in the ponds, although this is most likely not the primary cause.

Edwards et al. (1994b) recommend a maximum daily input of 50 kg DM ha^{-1} day^{-1} buffalo manure following the field trials with farmers. Supplementing this amount with triple superphophate and urea, aiming at the total N loading rate of 4 kg ha^{-1} day^{-1}, doubled fish yields compared to the application of buffalo manure alone (Edwards et al., 1996b). Even though buffalo dung is a rather poor manure, it may still be worthwhile to use it as long as resource-limited farmers do not have any better-quality manure or inorganic fertilizer available (Edwards et al., 1994b).

The daily loading rates in the case study ponds ranged from 0.1 to 12.4 kg DM ha^{-1} and are thus far below the application rates described above. Low manure rates have also been reported from a Vietnamese upland integrated aquaculture system. Here, farmers apply fresh manure twice monthly at the rate of 0.05 kg m^{-2}, totalling approximately 12 tons ha^{-1} $year^{-1}$ (Luu, 2001b), which is similar to the average annual application of 9.6 tons FM in the case study ponds. The manure application varied enormously between the ponds. The two ponds located in the upland area received considerably less manure compared to those ponds located close to farmers' houses and animal stables. Considering the low quality of buffalo manure as a pond input, the time and effort required for collecting and carrying the bulky manure, the application of manure to those distantly located ponds is most likely not rewarded.

The manure application in the case study farms did not follow a particular pattern and manure was applied only when it was on hand. Zhu et al. (1990) also showed that the frequency of manure application influences fish yields. In their experiments, the daily application of manure to fishponds resulted in higher fish yields compared to the application of the same amounts in 5 or 7 day intervals. For effective fertilization, it is widely recommended to distribute manure over the entire pond area (e.g. Yi and Lin, 2001). In the case study farms, manure was only dumped at a corner of the pond and not distributed. Considering the low value of buffalo manure, the low amounts applied by farmers as well as the rate and method of manure application, it is rather unlikely that the manure contributed substantially to fish growth in the studied ponds.

Cattle and pig manure played a much smaller role in the case study farms. Cattle manure showed a slightly higher N content (1.6% N of DM) compared to buffalo manure, whereas it was lower in pig droppings. The high DM (32.3% of FM) as well as the low N-content (1.1% of DM) in pig manure may be attributed to the presence of waste material from animal stables. The nutrient quality of pig manure is known to be highly variable depending on the breed, age, live weight, feed, etc. (Müller, 1980). The CP content of pig faeces has been reported to range between 11-31% (average 19%) of DM (Pearce quoted in Müller, 1980). Since the manure is derived from the local breed that is fed largely on products low in protein such as cassava tubers, the manure probably also exhibits a lower N-content compared to pigs fed on protein-rich feed.

The use of human waste as a pond input (Edwards and Little, 1995; Edwards, 2000) as well as crop fertilizer (Jensen et al., 2005) is a traditional, widespread practice in Vietnam. Also, in the study area, human excreta make up an integral part of nutrient recycling and are applied to ponds in several cases. The use of human excreta in crop production and aquaculture has been associated with a number of beneficial, but also health-jeopardizing effects, since it may contribute to infections caused by parasites in the faeces (Dalsgaard, 1996; Jensen et al., 2005).

Usually, higher fertilization is associated with an increase in plankton production (Nandeesha et al., 1984, Boyd, 1982). This was not the case in the present study, where there was not any apparent correlation between the amounts of manure applied and the abundance of plankton biomass in the individual case study ponds. The manure applied to the case study ponds did not seem to significantly contribute to the natural food production. This assumption is supported when looking at the plankton biomasses, which ranged between roughly 0.5 and 1.5 mg l^{-1} in the case study ponds. The biomass was determined by drying out the netted matter, which might also have comprised matter other than plankton; thus, those amounts may possibly overestimate the availability of the plankton biomass. Boyd (1982) summarized diverse works, in which samples of water were centrifuged in order to determine the weight of particulate organic matter. Here, average concentrations were 5.9 mg l^{-1} in unfertilized and 22.3 mg l^{-1} in fertilized ponds. Even when considering that the samples in those investigations probably had a higher moisture content compared to the oven-dried samples in the present study, the biomasses recovered from the case study ponds were much closer to the concentration in the unfertilized than the fertilized ponds.

The average number of phytoplankton individuals (with sizes ≥ 20 µm) counted ranged between roughly 15 000 (VL2) and 78 000 Ind l^{-1} (SV1) in the case study ponds. The number of phytoplankton individuals in a pond in Turkey ranged between 30 000 to 120 000 Ind l^{-1} over the course of a year, which was considered to be unsatisfactory. This low amount was explained by a short water retention time (0.6 day^{-1}; Demir and Kirkagac, 2005). In this experiment, the mesh size used for plankton collection was larger (55 µm) compared to the mesh size used in the presented study, thus indicating that there would probably be a greater difference to the presented study if the same mesh size was used. In experiments carried out by Spataru et al. (1983), a small mesh size (11 µm) was also used for counting the plankton individuals in manured polyculture ponds. Here, the average monthly phytoplankton densities reached up to 2 mil Ind l^{-1}, the individuals of zooplankton up to 4 600 Ind l^{-1}. The average number of zooplankton individuals caught in the case study ponds ranged between 86 and 267 Ind l^{-1}, much lower than densities reported in other studies. The average number of zooplankton individuals varied between 1 265 and 1 654 Ind l^{-1} in *Tilapia rendalli* ponds fertilized with Napier grass (Brummet, 2000); and up to 1 000 rotifers were counted per litre in ponds manured with either poultry or silkworm faecal matter (Nandeesha et al., 1984).

In the case study ponds, the dominant types of zooplankton were rotifera and nauplius, which corresponds with the other studies (Nandeesha et al., 1984; Brummet, 2000). However, the differences between the dominant phytoplankton classes in the various ponds cannot definitively be clarified here. They might possibly relate to the different species stocked in each pond. Spataru et al. (1983) found an inverse relationship between the type of fish stocked and the preferred plankton species it consumes.

With the exception of one sampling, the blue-green algae (Cyanobacteria) were not dominant in any of the ponds and no algal bloom was observed in the case study ponds. This is of importance since cyanobacteria may have adverse effects on fish (Sevrin-Reyssac and Pletikosic, 1990).

Compared to a study carried out by Demir and Kirkagac (2005), there was no clear seasonal change in the plankton availability between the summer and winter in the case study ponds. This may be related to the high fluctuations in water-flow as well as to an irregular fertilization regime used by the farmers. It also could be linked to the sediment-induced turbidity that mainly occurs during the hot and rainy season and which inhibits the photosynthesis during that time.

There were also differences in the plankton availability among the ponds. However, this can also not be definitively explained here, since its availability was probably influenced by a number of factors. Here, not only does the manuring and water management have an impact, but also the fish species densities and combination within the ponds.

The high water-flow in VL2, for example, might have contributed to the low plankton availability in the respective pond. It has been shown before that water residence time affects the phytoplankton production (Soballe and Kimmel, 1987). Also, Figure 42 shows a tendency of an inverse relationship between the plankton availability and the amount of water flow. While the water-flow is probably suitable for the production of the grass carp (as has been shown before by Prowse, 1971), it cannot be favourable for the production of those fish species that rely on natural food production rather than on the externally supplied feed material.

The availability of plankton may also be related to the turbidity caused by sediments. Pond SV1, for example, which was supplied with water that was relatively unaffected by erosion, had the highest availability of both phyto- as well as zooplankton.

The lowest number of phytoplankton individuals were counted in the ponds SV2 and VL2. In these two ponds, however, the proportion of silver carp to the total biomass output (Figure 44) was higher compared to the other ponds. In contrast, in the pond exhibiting the highest amount of plankton, SV2, both silver and bighead carp played only a minor role. These data indicate that the presence of silver carp, for example, might also have an effect on the phytoplankton availability.

The presence of silver carp may further depress the zooplankton biomass (Zhang et al., 2006). An overlap in the diets of silver and bighead carp has been previously reported, since the phytoplanktivorous silver carp may also consume zooplankton (Spataru, 1977, Spataru et al., 1983). Similarly, the bighead carp that predominantly feed on zooplankton are also known to consume certain amounts of phytoplankton (Spataru et al., 1983). In the case study ponds, both phyto- and zooplankton were discovered in the intestines of the silver and bighead carp in addition to considerable amounts of detritus (Table 36).

Also, other stocked species such as Nile tilapia have also been reported to filter plankton (Turker et al., 2003). The intestinal contents of the different fish species caught correspond to the known feeding habits of mud carp, mrigal, common carp, silver barb and tilapia (see Table 2) as well as of pirapitinga (FAO, 2006d). However, it became obvious from the investigation that the intestines of all fish caught contained considerable amounts of detritus. Fish probably compensated for the lack of “good food” (e.g. natural food) by consuming an increased amount of detritus. This has also been observed by Opuszynski (1981) in ponds that exhibited low zooplankton availability. Tilapia were observed feeding on manure of low nutritional value, which may be an additional sign of insufficient food availability in the case study ponds.

All of the data above demonstrate that the feed base for the non-grass carp species was rather limited in the case study ponds. Likewise, this demonstrates that the fish stocking combination and densities were suboptimal, since a proper combination of aquatic species at adequate densities is required for optimal yields in a polyculture system (e.g. Milstein, 1992; Azim and Wahab, 2003; Milstein et al., 2006). Thus, the quantity of fish should be in accordance with the productivity of natural food organisms as well as with the quantity and quality of the externally applied feed. The combination of species at the case study farms usually followed farmers' preferences as well as fish availability rather than a rational species composition. However, a proper "matching" of species is required in order to fully exploit the synergistic effects in a polyculture system. For example, the silver carp and bighead carp may feed on the natural organisms propagated by the grass carp faeces and thereby decrease the pond fertility, which is again beneficial to grass carp growth (Huazhu and Baotong, 1989). The inclusion of silver carp in a polyculture with small indigenous fish species and either mrigal or common carp did not affect the growth of common carp but led to a reduced growth rate of mrigal (Milstein et al., 2006).

7.3.5 Additional considerations associated with the local feeding practices

The ponds in Yen Chau are integrated into the overall farming system. Irrigation water is distributed among paddy fields and fishponds, feeds for different animals and fish are mainly derived from the farmers' own crop fields, and animal droppings fertilize crop fields and provide nutrients to the ponds. Some of the major obstacles for increasing levels of efficiency and production in IAA systems may derive from temporal, spatial or technological mismatches (Prein, 2002). In the study area, temporal mismatches occur as feed becomes limited in the wintertime, which can be deemed a minor problem considering the generally lower feed intakes of fish at low water temperatures. During the hot summer period, when fish are able to consume larger amounts of feed, high workloads often leave farmers with too little time to collect fish fodder. The high fragmentation of farms leads to spatial mismatches. Thus, ponds located far distances from farmers' houses are often supplied with less diverse feeds compared to those situated nearby. Usually, the fish in upland ponds receive only small amounts of manure and rarely any other feed inputs with the exception of leaves from upland plots. In contrast, ponds located next to the farmers' houses are often supplied with more diverse supplements of higher nutritional values, such as kitchen wastes. In addition, theft is a common problem in those ponds located far away from human settlements. Short-term competition between different farm sub-systems might occur, e.g. between livestock and fish regarding feed and labour availability or between crop production and fish in terms of manure, water and labour resources. In the case that farmers have to budget these resources, they tend to give preference to livestock i.e. large ruminants as well as to crop fields. A key factor for successful integrated farming is the timely, optimal abundance of outputs from one enterprise that can be utilized as inputs for another (Prein, 2002).

The use of grass and leaf material in the investigated pond system comes with certain adverse effects. The high moisture content and the bulky nature of much of the applied feeds demands high amounts of labour for its collection and transportation. However, in some cases, aquaculture activities can be combined with other farming tasks, e.g. the weeding of paddy fields simultaneously provides food for fish.

A further constraint may derive from the wastes (uneaten food, faecal material) that are produced from the huge amount of applied leaf and grass material that accumulates on the pond bottom. This can lead to critical water deterioration (e.g. through the consumption of DO), particularly when it is combined with poor feeding practices. This is predominantly a severe problem in the case of fibrous and coarse plants since they decompose slowly (Little and Muir, 1987). It is assumed that rice hulls and straw, for example, which are typically low in nutrients and high in fibre (see Göhl, 1981), deplete water quality rather than substantially support fish growth in the study area. The case study ponds tended to show (although there was no clear correlation) an inverse relationship between the daily feed amounts applied (Table 30) and the specific growth rates of the grass carp (Table 34). Contrary to the expectation, the growth of grass carp was lower in those ponds with higher amounts of applied feed. Chikafumbwa (1996) found that the application of high amounts (> 50 kg DM ha^{-1}) of Napier grass to Malawian *Tilapia rendalli* and *Oreochromis shiranus* ponds decreased the water quality and reduced fish growth. In a model established by Van Dam et al. (1993), Napier grass-fed tilapia ponds were considerably inefficient, and the majority of the grass was removed in sediments in the form of detritus.

The accumulation of organic matter and its mineralization products may lower the quality of the pond mud (Hussenot and Martin, 1995). This is of particular importance since the properties of the pond mud are considered to be very important for the well-being and growth of fish (Avnimelech and Ritvo, 2003). The degradation of organic material at the pond bottom requires oxygen. Intensive degradation may lead to the depletion of oxygen and, thus, the development of anoxic conditions. Under these conditions, other electron acceptors are used to mediate the decomposition of organic matter (e.g. by reducing $SO_4 \rightarrow S$ and $CO_2 \rightarrow CH_4$). Anaerobic conditions may affect aquaculture production through unfavourable conditions at the pond bottom. Additionally, this could lead to the diffusion of the reduced and potentially toxic materials like sulfides and methane from the sediment upward into the water column (Hussenot and Martin, 1995; Avnimelech and Ritvo, 2003). In the study area, bubbles that smelled like hydrogen sulphides (H_2S) were observed in a number of ponds, however, not in the case study ponds. These sulphides may be highly toxic for fish (Boyd, 1982; Avnimelech and Ritvo, 2003).

The use of redox potential is a useful measure for revealing the source of oxygen used in the mineralization of the organic matter (Hussenot and Martin, 1995). In the case study ponds, the average redox potentials in the pond mud ranged between 31 and 50 mV and the pH between 6.7 and 7.0 (Table 26). Optimum redox potentials in pond sediments are + 100 to + 200 mV, while values < - 200 mV are considered to be dangerous, since the reduction of sulphates to sulphides takes place at this level (Hussenot and Martin, 1995). In the present study, pond mud was collected and the electrode was placed in the middle of the mud sample. However, M. Frei (pers. commun.) stated that by applying this (commonly practiced) method, DO may enter the pond mud and, in this case, the redox potential values are frequently over-estimated. Thus, the actual values in the mud are probably lower than those presented in Table 26. In any case, the values are lower than they should optimally be and it is likely that the conditions in the pond mud were anaerobic rather than aerobic in the case study ponds.

Also, the measured pHs in the pond mud are in a range that is considered to be suboptimal for fish production. Optimum values for mud pH are 7.5 to 8.5, while pH < 7 might be dangerous for the fish (Hussenot and Martin, 1995). It is recommended to use lime in order to maintain a pH between 7.5 and 8.5, which allows for the best decomposition of organic matter (Boyd quoted in Hussenot and Martin, 1995).

While the feed applied in the case study ponds is quite rich in fibre, it is low in crude protein and therefore also in N. The daily N applications in the case study ponds ranged from 0.4 to 1.5 kg N ha^{-1} and are thus much lower than the recommended rate of 4 kg N ha^{-1} day^{-1} for semi-intensive (tilapia) ponds (e.g. Edwards et al., 1994a, 1996b; Suresh, 2003). On average, the N that was present in the form of fish and self-recruiting species made up 14% of the total net N applied by feed and manure in the case study ponds. This figure is similar to the findings from Edwards (1993), who investigated the N accretion in a semi-intensive Nile tilapia pond supplied with different fertilizers. Here, 15% of the fertilizer N was removed in harvested fish, only 2% of the N was released into the environment by draining the pond water and the remaining 83% had probably accumulated in the pond sediment. Compared to the N applied in the case study ponds, the N in the experiments carried out by Edwards (1993) was predominantly used in an indirect way, since it was supposed to improve the availability of natural food. Therefore, there was at least one extra step involved in the conversion of nutrients to fish, which usually leads to lower nutrient conversion efficiency (Edwards, 1993).

Considering that the N was mainly used as a direct fish feed in the case study ponds, the N accretion in the case study ponds was worse than in the fertilizer-supplied ponds described by Edwards (1993). In semi-intensive fishponds in China, N was also applied in the form of feed and manure. Here, the N produced in the form of fish made up 22.6% of the N applied in the form of feed and manure (Yuan et al., 1993); thus, this let to a higher efficiency in N accretion compared to the presented system.

The percentage of crude protein applied in the case study farms was 14% of the applied dry matter of total feed and manure inputs (data derived from Table 30) and 16% when considering only the green fodder mainly consumed by the macroherbivorous fish (data derived from Table 34). In both cases, it is much lower than the usual recommended dietary protein requirements of cyprinids reported in literature (25-50% of DM, Kaushik, 1995; 37% for grass carp fingerlings, Yongqing et al., 1994). The optimum percentage of protein in the diets depends, for example, on the content and composition of amino acids. Although the percentage of protein was similar in a pellet diet and a lettuce diet, the protein synthesis in grass carp was significantly lower in the lettuce-fed group. The poor quality of the lettuce diet has been attributed to the deficiency in methionine as well as the poor digestibility and low energy content of lettuce (Carter et al., 1993).

The use of protein for energy purposes is usually high in carp as is the case with other teleosts (see Kaushik, 1995). Therefore, the ratio between dietary protein (commonly the most expensive nutrient) and the availability of non-protein energy is important for an economical use of protein. By applying more digestible energy, the efficiency of dietary protein utilization is enhanced and the N lost into the environment reduced (Kaushik, 1995). In the case study ponds, the average ratio between the applied CP and GE was 7.9±1.1 mg kJ^{-1} (~ 33.0±4.5 mg $kcal^{-1}$; calculated from Table 30). The optimum ratio between protein and energy has been found to be 104.7 mg $kcal^{-1}$ in the case of grass carp fingerlings (Yongqing et al., 1994) and in a range of 18-20 mg kJ^{-1} for cyprinids as summarized in the review from Kaushik (1995). This shows that besides the low availability of CP, the inappropriate protein to energy ratio probably also contributed to the low growth rates of the fish in the study area.

7.3.6 Possible pathogens of the fish diseases

Frequently occurring grass carp mortalities caused by diseases are considered to be the main constraint in fish culture in the study area. Losing fish equals high monetary losses for the farmers and is to a large part responsible for the low fish yields in Yen Chau ponds. In general, farmed grass carp are rather susceptible to various diseases such as haemorrhagic disease through the agent reovirus as well as septicaemia, enteritis or erythrodermia caused by various bacteria (e.g. *Aeromonas sobria, A. hydrophila, A. punctata, Pseudomonas fluorescens*). Also, diseases caused by tapeworm, helminth, protozoan extoparasites and copepods occur in grass carp (FAO, 2006b). The appearance of a particular grass carp disease, which in Vietnam is called Red Spot Disease (RSD), has been reported from different Vietnamese areas, both in the highlands and lowlands (Luu et al., 2002; Van et al., 2002). The term for the disease comes from the presence of red lesions on the bodies of fish. Other symptoms are haemorrhage, scale loss, swollen vent and darkened skin (Van et al., 2002). Comparing the RSD symptoms with those observed in Yen Chau, it is quite likely that at least a portion of the fish experience this same disease in the study area. According to Van et al. (2002), RSD is the major constraint to improving output from freshwater aquaculture in Vietnam. From 145 farmers in two provinces in Northern Vietnam, 81.4% of farmers faced fish disease problems during the growing cycle; out of them, 83.1% of the observed diseases can be characterized as RSD. RSD seems to have a seasonal pattern and occurs mainly in March-April and October-November (Van et al., 2002). However, grass carp diseases in Yen Chau occurred from March until November with peaks from June to September. RSD was first reported in 1962 in Ninh Binh Province (Ha quoted in Van et al., 2002), and since then, it has spread to almost all Northern Vietnamese provinces (see Van et al., 2002) including to Yen Chau district around 1996. Besides RSD, also haemorrhagic disease caused by reovirus occurs in Vietnam (Yulin, 2006) including Son La province (K.V. Van, pers. commun.).

Nhien et al. (2000) identified *Aeromonas hydrophila* as the pathogen of RSD in grass carp. K.V. Van (pers. commun.) also attributes RSD to this agent. The occurrence of fish diseases caused by *A. hydrophila* is also a big challenge in Chinese carp aquaculture (Ye, 2001). *A. hydrophila* probably contributed to disease-related problems in the Zhejiang Province in China (Nielsen et al., 2001). It is a ubiquitous freshwater bacterium found within the aquatic environment and its occurrence is often associated with an abundance of organic matter in the aquatic environment (Schubert quoted in Reichenbach-Klinke, 1980; Hazen quoted in Jeney and Jeney, 1995). Since fishponds in the study area exhibit muddy water with high amounts of organic material from applied feeds, fish are probably constantly exposed to infection. *A. hydrophila* belongs to the natural bacterial flora of fresh water fish. However, some pathogenic strains can be found among those bacteria (Reichenbach-Klinke, 1980). Conflicting views have been expressed as to whether *A. hydrophila* is a primary or secondary opportunistic pathogen (Jeney and Jeney, 1995). The pathogenicity of these bacteria often seems to be associated with stressed or compromised hosts (Jeney and Jeney, 1995; Heuschmann-Brunner quoted in Reichenbach-Klinke, 1980). Primary causes can be in the form of viral or parasitic infection, sudden changes in environmental as well as nutritional or husbandry status (Jeney and Jeney, 1995). M. Crumlish (pers. commun.) recommended taking extreme care when indicating that *A. hydrophila* is the causative agent of the late phase or even any phase of RSD. Since *A. hydrophila* is very easy to recover and grows very quickly, particularly in tropical environments, these bacteria can easily be recovered and the respective disease is therefore attributed to this agent. This assumption can be strengthened by the fact that often only dead fish can be sampled for bacterial recovery, which does not provide the most accurate results (M. Crumlish, pers. commun.).

However, Quiya et al. (2003) attributes the RSD to the grass carp haemorrhage virus (GCHV), a synonym for grass carp reovirus (Yulin, 2006). The causative agent of RSD has been examined and found to be very similar to a GCHV strain in China (Quiya et al., 2003). The haemorrhagic disease was first discovered in China in 1972. Typical external symptoms include exophthalmia, dark body colour and haemorrhages at the base of the fins, gill covers and mouth cavity. Besides grass carp, other fish species, such as bighead, silver and common carp can also carry this virus but do not show the symptoms and mortalities. However, they can be involved in transmitting this disease (Yulin, 2006). Usually fry and one-year-old fingerlings are infected and only occasionally do infections occur in fish that are 2-3 years of age. This disease leads to high mortalities of fingerlings in China and appears most frequently at temperatures between 25 and 28°C. Yulin (2006) distinguishes haemorrhage disease from RSD, which he attributes to bacteria. The author asserts that a mixed infection with bacteria or secondary bacterial infection can often lead to similar clinical and pathological changes.

However, it seems that up until now, the agent of RSD has not been completely identified. Within the framework of the “Uplands Program”, further research has recently begun, which attempts to identify the responsible pathogen(s). It might be the case that both the reovirus and the bacterium *A. hydrophila* combined with compromised hosts may lead to the disease known as RSD.

Diseases caused by fungi were also reported from the nursery/hatchery of Yen Chau. However, fungal infections are a persistent problem in warm water hatcheries with the rapid proliferation of dead eggs and spreading to the adjacent healthy eggs (Jeney and Jeney, 1995). Other diseases occur less frequently and seem to play a minor role in the study area.

7.3.7 Further potential contributors to the susceptibility to diseases and the low growth rates of fish

As mentioned above, some agents such as *A. hydrophila* are facultative pathogens; thus, they are always present in the water surrounding fish and can invade a compromised host and exacerbate its condition (Jeney and Jeney, 1995). Water temperatures that drop 10°C may become immunosuppressive for grass carp (Yang and Zuo, 1997); however, during disease outbreaks, water temperatures were in an acceptable range for grass carp. Environmental stress factors that predispose fish to the bacterial disease haemorrhagic septicaemia include an increased bacterial load in the water, particulate matter in the water, handling (especially after over-wintering at low temperatures), crowding, low DO, chronic sublethal exposure to heavy metals or pesticides (Wedemeyer and McLeay quoted in Jeney and Jeney, 1995).

It is quite likely that fish are frequently stressed in the study area by means of inappropriate handling, low DO and the potential entry of pesticides, detergents as well as sediments from the uplands, which may carry heavy metals (e.g. as a result of the weathering of rocks and soils) into the pond system. Metals may accumulate in the organs of fish including common carp and tilapia that are raised in polyculture ponds; this has been demonstrated by Adeyeye et al. (1996). Liao et al. (2006) showed that the environmental metal stressor is an important determinant affecting population dynamics of disease transmission by modelling the effects of metal cations (CD^{2+}, CU^{2+} and HG^{2+}) on the susceptibility of hard clam (*Meretrix lusoria*) to birnavirus. They support the theory that aquaculture species exposed to chemical stressors are immunosuppressed and that this suppression may be associated with an increase in disease susceptibility and mortality.

Another factor that might chronically stress fish in the study area is the use of detergents in canals that supply water and in the ponds themselves, even though those substances are rarely found in concentrations lethal to aquatic organisms (Alcaraz et al., 1993). However, detergents may have damaging effects on gills, which has already been shown by Schmid and Mann in 1961 in the case of trout. The exposure to a detergent affected growth and thermic responses of juvenile grass carp under laboratory conditions (Alcaraz et al., 1993). Thus, the superior incipient lethal temperature decreases with an increase in the detergent concentration.

In the study area, paddy fields and fishponds are very closely linked. It is likely that pesticides from the fields may enter into the ponds either through the entry of water or with the feeding of contaminated fodder. Even though most of the farmers reported that they try to stop the water flow for at least one day after pesticide application and that they avoid feeding fodder from recently sprayed fields, pesticides probably reach fish through leaching, after rainfall as well as through fodder collected from shared canals. The pesticide fenobucarb was still detectible in duckweed samples collected 24 hours after farmers' application of it to fields (Figure 21).

In the interview surveys (see 3.2.3 and 3.2.6) it was evaluated whether there is an obvious connection between pesticides and the grass carp mortalities observed in the study area. Fish mortalities after heavy rainfall were also reported from the mountainous Thai Nguyen Province in northern Vietnam regarding fishponds located in the valleys. The mortalities have been associated with the washout of insecticides applied to tea bushes on the hillsides (Van et al., 2002). Farmers in the Mekong Delta also noticed that the use of pesticides might undermine their fish culture activities (Nhan et al., 2007).

Most of the typical pesticides applied in the study area are classified as being slightly to moderately hazardous, but some of these (e.g. the active substance edifenphos) are considered to be highly hazardous according to the World Health Organization (WHO, 2002). For example, edifenphos is an organo-phosphorous compound (WHO, 2002). Some of the typical signs of fish poisoned with organo-phosphorus pesticides match those observed in the grass carp of the study area, such as darkening of the body surface at the onset of uncoordinated activity (Svobodova et al., 1993). However, other symptoms differed, including the noticeable production of mucus on the body surface and in the gills (Svobodova et al., 1993). Not only the active ingredients themselves should be of concern, but one should consider the degradation products as well as other chemicals in pesticide formulas, which may in some cases be more toxic to fish than the original active ingredient itself (Svobodova et al., 1993). A typically used substance in the study area is trichlorphon, which may degrade to the more toxic compound dichlorvos (Svobodova et al., 1993).

Even though there is some evidence that pesticides enter ponds in the study area, it is rather unlikely that they directly cause fish mortalities. Pesticides are applied during the rice culture seasons (Figure 17), and fish mortalities also occurred in November, a time when no more pesticides are applied to the rice fields. In addition, grass carp mortalities have been observed in ponds that are not linked to the paddy field area. However, pesticides probably contribute to a chronic stress on fish, which therefore makes them more prone to diseases. Within the framework of the "Uplands Program", further research on this topic is ongoing in the study area.

Dongmeza et al. (2009a) found variable amounts of antinutrients in the different feed materials applied in the study area, e.g. in the case of cassava leaves. Several reports exist concerning both health-promoting as well as health-jeopardising effects being associated with the consumption of antinutrients (Francis et al., 2001b, 2002).

In the study area, cyanogenic glycoside-containing cassava products are applied on a regular basis. These glycosides (linamarin and lotaustralin) can be broken down into free cyanides (hydrocyanic acid, HCN) by hydrolytic enzymes (see Heuberger, 2005). The average cyanide contents of the cassava leaves used in the study area range between 205 and 335 mg HCN equivalent kg DM^{-1} depending on the season of sampling (Dongmeza et al., 2009a). The leaves' HCN contents, however, are lower than those reported from other untreated cassava varieties (Fasuyi, 2005; Hang and Preston, 2005).

It is possible that the well-being of the grass carp in the study area was jeopardised by a continuous sub-lethal intake of cyanide. Apart from an acute cyanide intoxification and death, chronic exposure to sub-lethal levels may lead to a number of diseases such as "konzo" and "tropical ataxic neuropathy" in humans (Ernesto et al., 2002; Cardoso et al., 2004). Ingested cyanide may be detoxified with a combination of cyanide-reactive sulphur. Cardoso et al. (2004) showed that up to almost a fourth of the essential sulphur-containing amino acids, methionine and cystine, which are found in cassava flour consumed by children, were used to detoxify and convert cyanide into thiocyanate, which is then excreted with urine. Hence, without an additional source of these amino acids, protein deficiencies might also impair the health of those children.

Malnutrition has also been observed in rats fed solely a cassava diet. They had a significantly higher plasma thiocyanate level compared to rats fed a control diet (Osuntokun, 1970). Also, fish fed cyanide-containing feeds have shown low growth rates (Tan, 1970; Hossain and Jauncey, 1989; Dongmeza et al., 2009b). In pond CK1, for example, the high intake of untreated cassava leaves might not have only contributed to the low growth rates of the grass carp (6.4.1) but also to their susceptibility to disease.

The application of large amounts of cassava leaves might impair the water quality not only through the high amounts of organic material but also through a washout of cyanogens into the body of water. Simple compounds of cyanides in water (nondissociated HCN, simple CN ions) may be extremely toxic to the majority of fish species, with lethal concentrations in the range of 0.03 to 0.5 mg l^{-1}. Its toxicity is even enhanced with high water temperatures and low DO contents (Svobodova et al., 1993). Although thiocyanates (SCN-) are considered to be less toxic than cyanides, low doses of thiocyanates in water can reduce the feeding rate of tilapia (e.g. at 1.02 mg l^{-1} to half of that in the control group) and lead to an opercular movement at a dose of 4 mg l^{-1} at 28°C (Bhunia et al., 2000). Some of the symptoms associated with cyanide poisoning are increased depth of respiration, nervous disorders and loss of equilibrium (Svobodova et al., 1993), similar to those described from thiocyanates (Bhunia et al., 2000).

The potential entry of HCN into a case study pond by means of the application of cassava leaves over the course of 24 hours has been calculated on the basis of the maximum daily amount applied by CK1 (4 kg DM). Considering the average concentration of cyanides in the leaves during the hot season (335 mg kg DM^{-1}, Dongmeza et al., 2009a) and the proximate volume of the case study pond (575.64 m^3), approximately 2 µg l^{-1} HCN is washed out into the water. Assuming that all of the HCN accumulates in the water and does not biodegrade, the lethal concentration of 0.3 mg l^{-1} would be reached after 15 days. In fact, not all HCN is washed out from the leaves (e.g. only 30.9% for leaves steeped in water for 24 hours; Fasuyi, 2005). Leaves are eaten by the fish and transformed into the less toxic thiocyanate, and the water is partly exchanged by means of the water-flow. Additionally, HCN may also degrade to an unknown extent, which makes it extremely difficult to estimate the HCN concentration in the pond. For a better understanding, HCN levels in pond water should be measured in future research in order to assess whether cyanides might contribute to the mortalities of the grass carp in the study area.

A direct linkage between grass carp mortalities and the use of cassava is rather unlikely. In farm SV1, for example, grass carp mortalities occurred but cassava played only a small role in this respective pond. Toxic plant substances may also come from the timbers and bamboo that are occasionally kept in ponds for a longer period of time (5.2) as well as the “green manure”, Siam weed. The intake of cassava by-products combined with Siam weed, for example, through the affinity of methaemoglobin to cyanide, may lead to the formation of cyanmethaemoglobin, an oxygen depleting compound in the blood (Datta and Ottaway quoted in Fasuyi et al., 2005). However, further research would be required to clarify the impact of those observations.

Even though the above-mentioned impacts of heavy metals, detergents, pesticides and cyanogens into the ponds are all rather unlikely for directly causing grass carp mortalities, they might all contribute to an overall weakening of fish, thereby making them more susceptible to disease and they may negatively effect the growth of fish.

7.4 Impact of the local fish production on the livelihood of fish farmers and rural people

Even though the yields in Yen Chau ponds are relatively low, the benefits of farmers and rural people from fish production can be considered to be rather high. The effects of fish production on the livelihoods of the local people are manifold; some of these effects are demonstrated in Figure 47. Fish farmers not only consume aquatic products themselves, but they give them to neighbours and friends. They also contribute to the supply of fish at local markets through sales, which potentially leads to higher fish consumption by non-fish producing households.

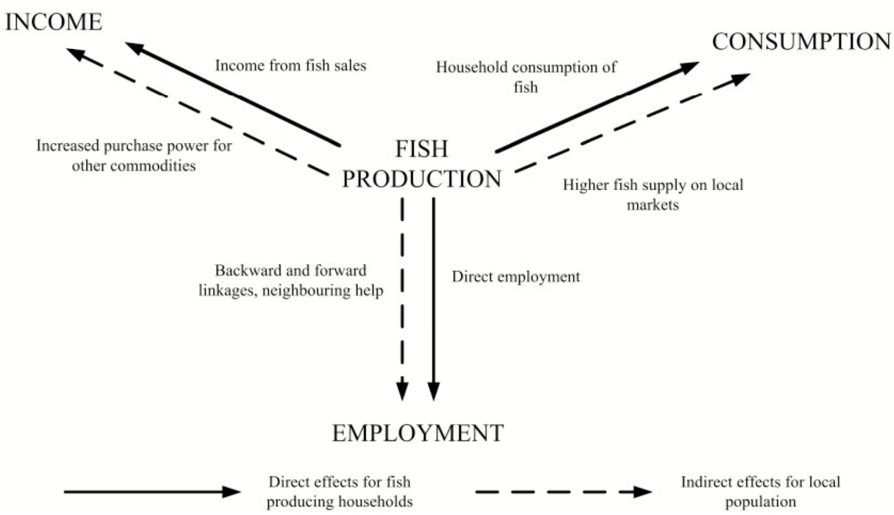


Figure 47: Effects of fish production for fish producing households and non-fish producing rural population

Interviewed farmers reported the sale of approximately 1.4 tons of fish when the data was converted to a year, which was similar to the figure provided from the monitoring of the case study farms (1.3 tons ha^{-1} $year^{-1}$). In addition, the case study farmers caught an average of 0.67 tons ha^{-1} $year^{-1}$ of fish and self-recruiting species for their own household consumption and for giving away as gifts. Thus, from all of the harvested fish and self-recruiting species, roughly two-thirds were sold, while one-third was utilised in other ways. Both fish production for income generation and fish production for household consumption were the major motivators for producing fish, which has also been noted by Nhan et al. (2007) in the case of fish farmers in Vietnams' Mekong Delta.

Often, fish farmers mentioned during the interviews that they consider themselves to be richer than non-fish producing farmers; similarly, they regard aquaculture as a lucrative business. The interviewed fish farmers considered fish to be the third most important product for income generation, following maize and cassava. Even though the average ratio of the pond to the total farm area was only 8.8%, the relative share of income from aquaculture production of the total household income was 12% in 2004, which also considers the farms with no fish sales in the year under consideration. However, the income does not automatically point to the standard of living on a farm, since the high share of household consumption is completely ignored in this figure (6.5.3). The farmers of VL2, for example, had to spend a part of their income on buying rice since their farm production was relatively market-orientated; it was therefore not enough to satisfy their own food requirements. Also, the income split between crop and fish production probably overestimates the benefits of crop production since the major income from the latter comes primarily from maize and cassava. These products are almost exclusively sold, whereas a high share of the pond produce is consumed within the households. Therefore, the ratio of income from fish production to the total farm income gives only a rough idea about the importance of fish production on these farms.

Yen and Binh (2005) reported that fish farmers in Ham Yen district/Tuyen Quang province (Vietnam) could receive an annual income of 3-4 mil VND from a well managed 800 m^2 pond, which is equivalent to the income of two high-yielding rice crops from 2 500 m^2 of paddy fields. However, it is not known how this figure has been calculated. For comparison, the average revenues (without consideration of the costs) received by the farmers in the study area during the major rearing period were approximately 4 mil VND based on a 800 m^2 pond.

A clear picture of the profitability of fish production of the case study ponds can be seen in Table 40. All farms made a profit from fish production, despite fish mortalities in four of the six ponds, theft in SV2 as well as partly overvalued costs. In this calculation, costs of the major feeds applied to the ponds were assessed on the basis of the labour required for its collection. In the case of feeding weeds from the paddy fields, for example, the labour costs were attributed to the pond sub-system as feed collection. In fact, those costs must be allocated to the rice sub-system as labour inputs required for weeding. In addition, labour costs were assessed according to typical payments for off-farm work. It should be considered that the ability to work off-farm depends on diverse factors such as the age of workers. Often, fish farming, like the raising of livestock, is carried out by the older people on a farm. For those people, there are usually less off-farm opportunities, which is the case with the relatively old and invalid cooperating farmer from CK2. Here, the opportunity costs are probably much lower and the profit is likewise higher. Despite the possible over-valuing of the costs, the average profit was roughly 1.15 mil VND year^{-1} from the case study ponds. Since the farmers usually owned between 2 to 3 ponds, the total profit from fish production per farm was even higher. Based on farmers' profits per hour of labour, the case study farmers made a profit of 5 700 VND on average. Comparing this figure with the daily income that can usually be obtained by working off-farm (15 000 – 30 000 VND for a full day), it can be shown that from an economic point of view, working off-farm is not a good alternative to fish farming. All of these calculations affirm farmers' statements that fish farming is indeed a lucrative business.

The increase in fish prices over the past few years (see 5.1.5) can probably be attributed to a higher demand caused by a higher number of consumers with an increased purchasing power. During the study period, the road no. 6, which connects Yen Chau with the country's capital Hanoi and provincial capital Son La, was under construction. This caused a greater presence of construction workers and later, after the road was upgraded, more transit traffic. Both of these factors probably contributed to the higher demand for fish. A further reason for the price increase may be due to the temporary decrease in the availability of poultry meat due to the prohibition of its sale after the appearance of bird flu (H5N1).

Many farmers stated that because of the production of fish, they are not forced to buy these products, which demonstrates the high importance of these commodities for the nutrition of Black Thai farmers. Lem et al. (2004) reported that around 80% of the Vietnamese population like to eat fish, which is based on economic, nutritional and health-related reasons. In the interview-based surveys, farmers estimated a monthly consumption of 7.6 kg fish per household, which corresponds to roughly 1.5 kg per capita. It can be assumed that this figure is quite reliable. In those case study farms that received the majority (but not all) of their aquatic products from the investigated ponds, the monthly per capita consumption was around 1.2 kg.

In order to calculate the contribution of fish to the protein requirements of the Black Thai farmers households, the following assumptions have been made: the average five-person household with a mean body weight of 50 kg per person (including children) and a daily requirement of 1 g protein per kg body mass has a total annual protein requirement of 91 kg. The total fish consumed over a year (91.2 kg) consists of 75% edible parts and contains a protein content of 18% for the edible parts (FM). It therefore contributes 12.3 kg of protein to the farmers' diets. This corresponds with 14% of the total protein requirements. Assuming that 50% of the total protein is fulfilled by animal protein, which is widely recommended, then fish protein accounts for 27% of the animal protein requirements. The figure calculated in this study is only a rough approximation, since it is based on a number of assumptions, but it shows that fish protein contributes significantly to the protein requirements of farmers. However, it is not known how much total protein is consumed and if the protein requirements are even completely fulfilled in the farmers' diets, which also exhibits other protein sources such as meat, non-fish aquatic products, eggs and tofu. Edwards et al. (1996a) calculated that about 250 kg of fish are required for a five-person household to satisfy the optimal nutritional needs of a fish-eating society. This assumes that 50% of total protein is fulfilled by animal protein and 75% of the animal protein is derived from fish.

Dey et al. (2000) stated that the average per capita fish consumption of rural fish producer households is much higher than that of non-fish producing households in countries such as Vietnam. A goal for further research may be the comparison in protein intake between a fish producing and a non-fish producing household in the study area. This is of special importance considering that 41% of people in the Northern Vietnamese mountains are considered to be malnourished (Luu, 2001a).

Small fish often reach relatively low prices on local markets, this being the case with tilapia and other self-recruiting fish, which rarely exceed body weights of 100 g. Black Thai farmers usually eat these small fish fried whole, including the inner organs and bones. Small fish are generally more nutritious gram-for-gram than large fish (Bouis, 2000), and they probably supply a large number of nutrients to a given household. Jensen (2001) calls the consumption of small fish with bones "the milk of Southeast Asia", since it may constitute the most important source of calcium in the diet. Calcium absorption has been found to be similar comparing small indigenous Bengali fish and skim milk (Hansen et al., 1998). Larsen et al. (2000) also showed that calcium from small fish with bones was available to rats, although to a lower extent than calcium from milk. Since milk is not a part of the traditional diet of the farmers in the study area, the consumption of small fish probably constitutes a valuable source of calcium in their diets. Fish can also supply Vitamin A. Roos et al. (2002) have found fish species with very high Vitamin A concentration among the commonly consumed fish in Bangladesh. Vitamin A is mainly concentrated in the eyes and visceral parts, which are fish parts that are also consumed in Yen Chau when small fish are eaten whole.

Even though the consumption of fish is usually associated with a number of healthy effects, the consumption of raw fish is a habit, which in contrast can jeopardize a person's well-being. *Chlonorchis sinensis* is a liver fluke that is frequently found in raw fish consuming populations in Asian countries and that may cause clonorchiasis (Lucius and

Loos-Frank, 1997). Kino et al. (1998) examined stool samples of 306 residents in Ninh Binh Province (Northern Vietnam) and found this infestation in 13.7% of the cases. The life cycle of *C. sinensis* occurs exclusively in ponds, and therefore the consumption of raw pond fish is probably a major source of infection. Upon checking large silver carp from local ponds, 100% of the fish were infected with metacercariae (Kino et al., 1998). Black Thai farmers regularly eat raw fish (e.g. silver carp) that they catch from their ponds. Better information of the locals regarding the health-jeopardizing effects of such a consumption habit could be a small step towards improving peoples' health status in the region.

Aquaculture activities not only provide employment for the fish farmers' families who are directly involved, but also for helping neighbours who do not receive money but instead a regular share of the harvests. In the local aquaculture activities, men as well as women are actively involved. Some activities, such as the catching of small self-recruiting species, are exclusively carried out by women. This differs from an IAA system found in northeast Thailand, in which all fish farming activities were clearly male-dominated (Setboonsarng, 2002). With increasing aquaculture activities, backward (e.g. hatcheries and nurseries, suppliers of pond inputs) and forward enterprises (e.g. trading and processing of fish) may also be developed or expanded, bringing along further opportunities for employment.

Besides the benefits mentioned already, ponds also have additional values, e.g. they can serve as "saving accounts", since farmers can raise fish for a longer period of time and harvest in the case of a pressing need for cash. Ponds can also serve as "buffers" against food insecurity during times of food shortages. Besides fish, poultry are also slaughtered for household consumption, which may provide relatively small units of animal protein, similar to fish. During the research period, poultry diseases led to the loss of a large number of poultry, and its sale was temporarily banned due to the occurrence of bird flu. In this case, for example, fish provided an alternative protein source. Another important function of ponds is the maintenance of kinship connections, which has also been reported by Luu (2001a). Small-scale aquaculture ponds can serve as "a means of receiving guests for funerals and weddings, which otherwise would represent significant shocks to farmers' livelihoods" (Luu, 2001a). Furthermore, ponds can also serve as storage areas for water in times of drought and provide fertilizer for crop production, although this is currently not practiced on a large scale in the study area.

7.5 Sustainability of the current aquaculture system and anticipated development

The typical starting point of aquaculture activities is using any available plant residues and manure as pond inputs - as is the case with the current state of the aquaculture system in the study area. With better access to markets, farmers typically start to intensify their fish production. Typical evolutionary stages start with the use of inorganic fertilisers and low cost feeds plus aeration and health management and go up to more market-oriented systems with pellet feeding as a main input (Prein, 2002).

While in the past, Yen Chau farmers' major concern was the supply of fish for their household consumption; they have become increasingly more market-oriented, which is probably influenced by better access to markets and information through media. Currently, farmers are obviously motivated by both income generating opportunities as well as improved food supply.

In Yen Chau, the aquaculture in its current stage has a positive impact on the farmers' households. Currently, the production of carp is relatively profitable since it requires low investment and maintenance costs and its produce obtains relatively high prices, since the market is not yet saturated.

However, when the question arises whether the aquaculture system – in its current form — is sustainable, it can be assumed that it is not. Sustainable agriculture (as well as aquaculture) has ecological, social and economic aspects. Therefore, when the sustainability of a system is assessed, all three of these perspectives should be considered (compare review of Yunlong and Smith, 1994). Alternatively, as proposed by AIT (Asian Institute of Technology), aquaculture should be sustainable in terms of production technology, social, economic as well as environmental aspects (see Edwards et al. 1996a; Edwards, 1998). Edwards et al. (1996a) state that systems based on poor quality inputs, such as buffalo manure and fibrous plant materials, may be unsustainable. As mentioned before, both buffalo manure as well as fibrous material were inefficiently converted into fish biomass and additionally may have led to the deterioration of the water quality in the studied ponds. Considering the social dimension, e.g. the satisfaction of basic needs, then it can be argued, that even though fish provides valuable protein to farmers' households, the consumption rate is relatively low. Looking from the economic perspective, the actual system will probably not be able to continue in its current form, since it will be exposed to quickly altering markets.

Vietnam is a very dynamic country and the inhabitants need to rapidly and flexibly adapt to frequently changing circumstances. Despite progress occurring in all regions, there is still inequality between regions (ARMP, 2000), and the development gap between urban and rural areas has increased within the last few decades (Luu, 2001a). It can be expected that an increasingly intensifying aquaculture production in the better developed lowlands (e.g. peri-urban regions) may have a negative impact on remote mountainous areas, since cheap "lowland" fish might flood the market, even in fish producing regions such as Yen Chau. This possible scenario can also be supported considering the upgrade of road no. 6, which will most likely be a further impetus for trade activities and stimulus for fish movement. The increasing sale of lowland fish at the district market, which was observed during the study period, does already indicate this tendency. However, the increasing trade between different regions can be expected in the case of a number of commodities, which also reveals the potential for local farmers to export certain products such as fish to other regions. Further change will probably be influenced by Vietnams' increasing openness towards the world market as a result of its joining the WTO (World Trade Organization) in 2007. This will most likely have an impact on production patterns in many areas of the country, including that of the farmers in Yen Chau. In order to keep up with the overall development, the current aquaculture system needs to become more productive. If the system is not upgraded in the near future, aquaculture activities might not survive in the region.

7.6 Methods for improvement of the current aquaculture system

Considerably higher fish yields have been reached after small modifications in the management of stocking and harvesting techniques and improvement in feed supply in the northern Vietnamese Red River Delta (Luu et al., 2002). However, it is probably unwise to simply transfer technology that has been successfully applied elsewhere to the Vietnamese uplands. Also, the simple transfer of standard technology packages created by researchers has seldom fitted to the diverse and resource-limited context of most poor farming households (Edwards, 2000). Furthermore, ponds in controlled experiments performed often much better compared to those run by farmers (Edwards et al., 1996a; reviews of Lightfood et al., 1993 and Prein, 2002). Also, science-led development programs, though associated with a number of success stories (e.g. the Green Revolution), have often failed to increase the livelihoods of the rural poor in many locations (Grove and Edwards, 1993).

Through the broad study carried out in Yen Chau, which was conducted in close participation with the farmers, location-specific solutions can be developed that have the potential to improve the livelihoods of farmers in a sustainable way.

In order to improve the current aquaculture system, it is not enough to simply concentrate on modifications of the pond (and farm) management alone. For example, the use of fish seed that has low growth potential might negate the effects of improved feed application. Therefore, an upgrade of the overall system is required. A combination of improvement measures is proposed in the following, which are based on a) improvement of the pond system, b) expansion of the area used for aquaculture purposes and c) elimination of external restrictions. These measures affect the farmers, the research as well as the overall institutional and political framework.

7.6.1 Improvement of the pond system

It has been recommended that instead of providing a single technology, a broad range of technology options should be offered to farmers (Edwards, 2000; Yen and Binh, 2005). The current aquaculture system focuses on grass carp, but grass carp production has become a risky venture due to the occurrence of diseases that cause high fish mortalities. As long as the diseases cannot be prevented or treated, it seems unwise to focus so much energy on this fish species. Therefore, two modified systems are proposed: a modified grass carp-dominated system and a non-grass carp-dominated system. Considering that farmers in the region usually own more than one pond, they would be able to implement both kinds of systems in different ponds and thereby reduce the risk of losing so many fish from disease. General characteristics and modification measures of the two aquaculture systems are shown in Table 41.

In both systems, the first steps towards a modified system are simple improvements in pond management, which are expected to have a positive impact on the well-being and thereby also on the growth of fish. Aquaculture technology is considered to be relatively complex and knowledge-intensive; and local knowledge on aquaculture is usually limited compared to other farming activities (Prein, 2002; Nhan et al., 2007). Similarly, farmers in the region exhibit rather limited knowledge concerning basic aquaculture technology. Simple improvements in fish handling and pond preparation would probably bring about quickly attainable, positive impacts on fish production.

It was observed that farmers enter their ponds and move around in order to improve the availability of DO for their fish; however, this caused mud to swirl up with above-mentioned adverse effects. Also, the inappropriate handling of fish, such as transferring fish without tempering, may cause stress, reduce growth and increase their susceptibility to diseases (Appleford et al., 2003). After catching or transferring fish, fish mortalities were frequently observed.

Table 41: Characteristics and improvements of a modified grass carp-dominated and a non-grass carp-dominated system

Factors	Modified grass carp-dominated system	Non-grass carp-dominated system
General pond management	Improved handling of fish, removal of pond mud, dry-out pond bottom (if possible), use of lime, regular removal of crop leftovers	Improved handling of fish, removal of pond mud, dry-out pond bottom (if possible), use of lime, regular removal of crop leftovers
Cultured fish	Adequate species composition in order to obtain high growth rates	Decrease proportion of grass carp (e.g. 10%) and increase densities of other fish (e.g. 50% common carp, 10% silver carp, 10% bighead carp, 10% mud carp)
Feed base	Treatment (e.g. detoxification) of plant material, avoid application of high fibrous plants that have a low nutrient profile (e.g. rice straw), improved supplementary feeds for the non-grass carp species	Improving fertilization (use of organic and inorganic fertilizers), use of supplementary feed made from low-cost locally available ingredients, restricted use of green plant material
Water supply management	Better regulation of water flow, construction of water by-passes, use of simple airlifts	Reduction of water flow (or use of stagnant water), construction of water by-passes, use of simple airlifts

Besides the improved handling of fish, simple strategies in pond preparation such as drying out the pond bottom and liming prior to fish stocking are also generally recommended for reducing the risk of disease (K.V.Van, pers. comm.). Furthermore, the pond mud needs to be removed on a regular basis and could be used for crops instead of repairing dykes (currently, the most common use). Farmers in low-input IAA in the Mekong Delta, for example, recognized the use of nutrient-rich mud as being an important crop fertilizer (Nhan et al., 2007). The regular removal of the fibrous crop leftovers would probably also have a favourable impact on the water quality. However, all of these simple improvements require an appropriate dissimilation of basic aquaculture techniques, which is discussed in chapter 7.6.3.

The current grass carp-based system is restricted by issues such as disease(s), poor water quality (grass carp prefer clean water; FAO, 2006b), low growth rates, low temperatures in the wintertime, low quality of the applied fodder, etc. On the other hand, grass carp production has a number of advantages, which were previously mentioned and should not be dismissed. Therefore, it is probably unwise to eliminate this species from the ponds. This, however, is currently done by a number of farmers in order to avoid the risk of losing fish from disease. For the farmers who are still willing to continue with the grass carp-based system, the following modifications could be tested.

The average rearing period in the case study farms was 21 months (without considering the previous rearing period in nursery ponds). Typically, stocking occurs in the spring, which implies that the “average” fish is raised in the grow-out ponds over the course of two winters. Two winters means two periods where fish are kept in ponds at sub-optimum water temperature levels for grass carp, so they therefore exhibit low (or no) growth during those periods. Therefore, it would make sense to reduce the rearing period so that grass carp will reach marketable size after raising them maximally over the course of only one winter season. Raising grass carp in larger ponds and at lower stocking densities has been reported to positively influence the growth rates of this species, which was also observed in the case study ponds (see 7.3.3).

Besides stocking density, certain improvements in the feed base would also probably have a positive impact on fish growth. Some of the applied fodders appear to support the growth of grass carp as has been demonstrated in the feeding trials carried out at UHOH (7.3.3). In contrast, others are more likely to deteriorate the water quality rather than improve the growth of fish (e.g. rice straw) and should be reduced or avoided as feed.

In order to improve certain feeds that contain high levels of unfavourable antinutrients, farmers could employ some simple, feasible methods of detoxification before feeding these materials to their fish. A combination of shredding and sun-drying, for example, have been found to be an efficient technique in reducing the high levels of cyanogenic glycosides in cassava leaves (Fasuyi, 2005). Additionally, maceration and soaking cassava leaves combined with sun-drying greatly reduced the cyanide content compared to sun drying alone (Ng and Wee, 1989). In the study area, the sun-drying of cassava may be restricted during the rainy season. In this case, simply letting the leaves wilt may be a good alternative. The wilting of cassava leaves for 24 hours in the shade led to a HCN reduction of 58%; 82% of HCN was reduced when leaves were chopped and washed beforehand (Hang and Preston, 2005). However, it should be considered that all the above-described pre-treatments require additional labour, which is restricted in the study area; therefore, the costs and benefits of such techniques need to be evaluated.

Also, the production of high quality grasses and legumes is another option for improving the availability of nutrients for grass carp. Currently, a few farmers already produce Napier grass on pond dykes, which is then exclusively used as fish feed. Since the land is limited in the research area, certain fodder plants could be grown in (upland) crop fields, which would not only act as erosion and weed control but would also improve the fertility of the soil. Erosion can be considered a big problem in the region (see also Wezel et al., 2002a,b), which also influences ponds in a negative way with the entry of sediments. Potential fodder plants that could be used to prevent erosion include the grasses *Brachiaria brizantha* and *B. decumbens* as well as the legume *Stylosanthes guianensis*, which are probably suitable for the climatic conditions in the research area (Kerridge et al., 2000). Even though many efforts have been undertaken in the form of research and development projects in Southeast Asia, the adoption rate of farmers using fodder plants as erosion control has been rather low in the past, which has been attributed to a research that was too top-down, supply-driven and exhibited too little involvement of farmers (Kerridge et al., 2000; Roothaert et al., 2003). Yen and Binh (2005) reported that fish farmers in Tuyen Quang Province (Vietnam) started to expand their forages after working with a "Forages for Smallholders Project" and generally preferred grasses such as *Panicum maximum*, *Paspalum atratum*, *Setaria phacelata* since they are high-yielding, easy to cut, persistent and stay green during the dry season. Other important forage characteristics for the purpose of feeding fish include smooth, soft leaves and the ability to float on the water surface. Beside better feed supply to fish and improved natural resource management, the reduction in labour is also a reason to plant forages (Yen and Binh, 2005).

In addition to feeding fresh plant material, the use of pelleted feed has also shown great potential in grass carp production (Huisman and Valentijn, 1981), which is not discussed further here.

Since grass carp require water of low fertility (FAO, 2006b) and do not depend on the naturally occurring food items, the current system with a more or less constant water flow favours the growth of this fish species. Prowse (1971) observed in Malaysia that flowing water seemed to increase the ingestion rate of grass carp. However, proper water management with the option of letting water bypass the pond and regulating the water flow is also required for the grass carp-dominated ponds in order to avoid the entry of different kind of pollutants as was previously described.

In contrast to grass carp, the more or less constant water flow is probably less favourable for the other fish species in the polyculture system. It was previously mentioned that the water flow has a negative impact on the natural food availability. Natural food was generally low in the existing aquaculture system, which probably contributed to the low growth rates of the species that may utilize it. In order to improve the growth of the species in the non-grass carp-dominated system, the first step is a much more controlled regulation of the water flow in order to just compensate for evaporation and seepage.

In the non-grass carp-dominated system a species combination may be used that favours common carp. Common carp generally fetch high prices on the local market, prices that are even higher than those paid for grass carp. In contrast to the Chinese carp species, farmers may reproduce common carp themselves, which may save money and further help farmers become more independent of the unreliable seed supply from the hatcheries. Also, in the non-grass carp-dominated system, a certain proportion of grass carp should be stocked (e.g. 10%) in order to utilize the abundant leaf and grass material and to provide fish faeces for fertilizing the pond. Here, low amounts of green plants of comparatively high quality should be used to supplement the feed. Furthermore, grass carp stocked at low densities have shown extremely high growth rates in polyculture ponds as investigated by Sinha and Gupta (1975).

Also, tilapia can be stocked in those ponds provided that the husbandry practices are adapted to the cold winters in the region. Charo-Karisa et al. (2005) showed that smaller fish are more susceptible to lower temperatures than big fish; therefore, they recommend increasing the pre-winter body weights. The netting of tilapia prior to winter could also be a further option. Since tilapia are robust fish that feed low in the food chain and have a high importance for farmers' alimentation, it is probably not advisable to completely eliminate this species from farmers' ponds.

Natural food production needs to be stimulated in the non-grass carp-dominated system. This is done not only by means of decreased losses via the outflow, but a proper fertilization management is also required. Since buffalo manure is a rather poor pond input (with its adverse effects on the water quality as previously mentioned) and the abundance of other manures is restricted (e.g. through the scavenging features of poultry and the low availability of pigs), attention should be paid to other sources of fertilization. Once fish production becomes more market-oriented, the use of on-farm resources alone would typically no longer be sufficient (Edwards, 1998; Edwards et al., 1996a, 1996b). Edwards et al. (1996a) stated that the use of off-farm nutrients must be increased in order to permit a significant increase in production. The use of inorganic fertilizers is usually associated with higher intensification (Prein, 2002) and has been recommended in combination with buffalo manure (Edwards et al., 1996b). However, not only the type of fertilizer, but also the method of application, must be improved (see 7.3.4).

In order to improve the feed availability of the species stocked, in addition to fertilization, adequate supplementary feeding is required. The use of fish feed has to be tailored to the specific farming system and not just to the theoretical requirements of a fish without access to natural food (see Tacon, 1993, 1997b). The feed should preferably be based on nutrients, which complement the nutrients available in natural food organisms that are usually rich in protein (50-60% protein of DM in a mix of organisms; De Silva, 1993). The use of a nutritionally balanced feed is considered to be a waste of resources and an economically unsound practice (De Silva, 1993). The use of protein, which is typically the largest and most expensive part of an aquaculture diet (Southgate, 2002), should be further reduced in supplementary diets for semi-intensive aquaculture systems (De Silva, 1993). However, there are plenty of complex interactions between the natural food materials and supplementary feeding practices under semi-intensive culture conditions (De Silva, 1993). Up to now, these are poorly understood and further research is necessary in this field (Tacon and De Silva, 1997; De Silva, 2003a).

The production of artificial compounded feeds is one of the fastest expanding agricultural industries in the world (Tacon, 1997b). A typical component of compounded fish feeds are fishmeal and fish oil, which have been associated with a number of ecological concerns, such as the depletion of ocean stocks and the loss of energy through additional trophic levels. It has therefore been recommended to decrease the use of fishmeal and favour herbivorous diets for fish that feed at low trophic levels (see Naylor et al., 2000).

Since agro-industrial pellet feeds are relatively expensive, supplementary feeds could be formulated using on-farm or locally available ingredients. There are a number of feeds already available, such as rice bran, broken rice, cassava and maize, which may be used for the formulation of a supplementary diet. However, the focus should not only lie on the feed that results in the best fish growth performance. Tuan et al. (2008) tested the growth and food conversion of common carp by feeding them low cost feed from resources available in the study area. Control fish received a diet mainly based on fishmeal and performed best in the laboratory in terms of growth and food utilization. However, the profit (based on price of feed per kg of fish produced) was higher in the feeding group that was mainly fed locally available soy and maize meal.

Supplementary products such as (energy-rich) maize and cassava in conjunction with the natural food available may result in high growth rates of some of the cultivated fish such as common carp. Currently, these particular products are cash crops in the Yen Chau farms; however, the conversion of these products into high-value fish might be associated with a higher benefit for farmers and significantly higher fish production. This should be evaluated in future research.

Also non-conventional and locally available feedstuffs such as earthworms have been found to contribute to the growth of common carp (Tuan, unpublished data). Furthermore, the inclusion of certain leaves and grasses available in the region is also an option. The inclusion of low levels of (pre-treated) cassava leaf meal has been found to be a useful protein source for Nile tilapia (Ng and Wee, 1989). Installing an electric light bulb above the pond surface to attract flying night insects would be a further possibility for upgrading the feed base for fish.

Further, the methods of feed application could also be improved. For example, Yakupitiyage (1993) recommends cooking carbohydrate sources such as cassava tubers in order to improve palatability and digestibility of this material. The author also recommends mixing the cooked carbohydrates with other feed items and making a wet dough out of it, which would reduce feed wastes. Additionally, the use of pellet feed is an alternative.

In order to prevent insufficient DO in the ponds, the use of simple airlifts would be an option for incorporating DO into water. This is a technique that could be developed in cooperation with local technicians with locally available material (e.g. small turbines).

Some of the above-mentioned methods formulated for the non-grass carp-based system may also be applicable to the modified grass carp-dominated system. These methods include the application of improved supplementary feed for some of the non-grass carp species in the respective ponds as well as the use of airlifts.

In the next phase of the "Uplands Program", the performance of the proposed non-grass carp-dominated system will be tested on-farm. This part of the research will be carried out in close cooperation with farmers. In contrast to the presented study, selected contract farmers will produce fish according to the researchers' requests. Once the modifications are tested in the field and have shown good results (higher yields, higher profit, lower risk), it is expected that farmers are willing to adapt the developed modifications.

It frequently occurred during the interviews that farmers stated that they are not satisfied with the current output of their ponds; therefore, they seek measures that will improve productivity. The author of this book has no doubts that farmers are willing to employ some of the before-mentioned modifications despite a general attitude that can be described as risk-adverse and reluctant to overcome traditional attitudes. After watching an advertisement on television, two of the case study farms started raising pirapitinga although none of the farmers in their surroundings had any previous experience with this species. After the 2-day workshop that was organized in Yen Chau in connection with the present study, certain technical information that was new to the farmers was immediately adapted, put into practice and even spread among farmers (Steinbronn and Friederichsen, unpublished data).

However, the higher the intensity of the aquaculture system, the greater the requirement for inputs and consequent costs. The modified system can only be sustained when there is an obvious increase in yields as well as returns. Currently, farmers spend very little money on their ponds, which is understandable considering the high risk of losing grass carp through disease. However, once farmers are aware of the economical returns from modified aquaculture production, they would probably be willing to invest more money in commercial inputs for their ponds as they already do for crop production.

Besides intensification of the existing ponds, the expansion of the area used for aquaculture purposes is another option for increasing the overall fish output. However, the expansion of the pond area is restricted by the local political framework and the limited land area; it is therefore not discussed here. However, there are more ways to expand the area used for aquaculture purposes.

7.6.2 Expansion of the area used for aquaculture purposes

Water is an increasingly scarce resource in many developing countries, which increases the pressure to utilize it more efficiently. Future availability of fresh water for aquaculture production is perhaps the largest unknown factor for the future (Naylor et al., 2000). It has been suggested to integrate aquaculture into the irrigation systems (Little and Muir, 1987; Fernando and Halwart, 2000; Murray et al., 2002), which include irrigation reservoirs, canals and irrigated fields (Fernando and Halwart, 2000). Fernando and Halwart (2000) propose a flexible system of moving culture fish within a system of habitats, e.g. short-lived habitats could serve as nurseries and permanent water bodies for growing out fish. This system would have the potential of supplying fish year-round. Fish culture in storage systems, either extensively or intensively in cages, has been insufficiently investigated so far (Murray et al., 2002).

Currently, fish are produced in the Chieng Khoi storage lake with reported yields of roughly 200 kg ha^{-1}. Yields ranged between 56.6 and 469.1 kg ha^{-1} during a growth cycle in farmer-managed water reservoirs in the Vietnamese Thai Nguyen and Yen Bai provinces (Nguyen et al., 2005). In the reservoir of Eao Kao in central Vietnam, they ranged from 400 to 450 kg ha^{-1} (Phan and De Silva, 2000). Yields are usually lower in lakes since typical pond management, which includes the elimination of predators and optimal fish stocking, is often not possible on such a large scale (Little and Muir, 1987). Even though the catches from the Chieng Khoi Lake are probably relatively low, they obviously contributed to the market supply of fish. Culture-based fisheries have been promoted in order to increase aquatic food supplies and is considered to be environmentally friendly since it involves the use of existing bodies of water with minimal external inputs (De Silva, 2003a,b). Culture-based fishery is relatively new in Vietnam (De Silva, 2003b) and, so far, little scientific work has been undertaken regarding culture-based fisheries in Vietnamese reservoirs (Phan and De Silva, 2000). Instead of stocking fish by introducing them into the whole body of water, a more intensive fish production in cages could be an option. This technique also be applied during the hot rainy season in the Chieng Khoi reservoir lake.

In the study area, water is distributed among the different villages through a network of irrigation canals based on the traditional irrigation system “Muang Fai” (Hager et al., 2005). An important first stride toward reducing water loss would be the cementation of canals that are not yet supported by concrete. The production of fish in canals or streams is probably not a good option under the current conditions, since one can expect a low survival rate of fish due to highly fluctuating water levels, stress caused by heat in the case of shallow waters and the entry of pesticides as well as detergents. An additional constraint would be the high occurrence of theft of fish.

An option for expanding the area used for aquaculture purposes as well as promote more efficient water and land use could be the integration of fish culture into paddy fields, which is traditionally used in the terraced paddy fields in China (Kangmin, 1988; Lu and Li, 2006) as well as in the Northern Vietnamese mountains (Edwards et al., 1996a). Frei and Becker (2005) state that integrated rice and fish culture optimize the benefits of scarce water and land resources through complementary use and exploitation of the synergies between fish and plants. Integration can follow either a rotational or concurrent scheme (Kangmin, 1988; Dashu and Jiango, 1995). Rotational schemes can be observed in the study region (e.g. in the case of farm CK2) when, for one season, ponds are transferred into paddy fields. However, this practice is rare and is usually based on limited availability of manpower or other resources. Since farmers are not allowed to transform paddy fields into ponds without specific permission, the scope for this technique is rather limited as long as the local policy framework does not change. However, the more efficient method of rice-fish culture seems to be the concurrent scheme (Frei and Becker, 2005), where fish and rice are produced simultaneously. This technique has not yet been adopted in the study region. Increases in rice yields with the integration of fish compared to rice monoculture have been reported in literature (see reviews of Kangmin, 1988, Frei and Becker, 2005 and Lu and Li, 2006). In addition to the rice yields, fish can be harvested; the fish production in a carp/tilapia mixed culture in Bangladesh reached up to 935±29 kg ha^{-1} (Frei et al., 2007). Species reared in rice fields comprise common carp and tilapia (Kangmin, 1988) as well as silver barb (Little et al., 1996; Haroon and Pittmann, 1997; Vromant et al., 2002a,b), which are all species commonly reared in the study area. Special advantages of rice-cum-fish farming include weed and pest control through fish as well as the addition of fertilizer through fish droppings (see reviews Kangmin, 1988, Frei and Becker, 2005 and Lu and Li, 2006). Many farmers in the study region stated interest in expanding their pond area. Farmers who raise juvenile fish in paddy fields and transfer them later to their ponds could also benefit from higher fish output per unit of pond area in addition to the previously defined advantages of this system. Flooded fields can serve as a “richly laid table” for fry and fingerlings (Sinha, 1985). Even farmers without ponds could participate in the lucrative fish business. Since the use of pesticides in paddy fields may harm fish in ponds, the integration of fish into paddy fields can act as an entry point for IPM (Gupta et al., 1996).

However, integrated rice-fish farming requires a certain level of skill, appropriate infrastructure and logistics, so a policy framework for promoting this technique is needed (Frei and Becker, 2005). In addition, special emphasis must also be given to the availability of fingerlings at affordable prices and appropriate times (Gupta et al., 1996), which is often not being the case in the study area.

7.6.3 Elimination of external restrictions

One of the major restrictions in the current aquaculture system is the low quality of fish from the local hatcheries. The local hatcheries need financial and technical knowledge assistance in the future in order to increase their gene pool as well as to improve the breeding performance of fish. Here, national policies could provide increased support. Disease-free fish with a good growth potential are required for all further aquaculture ventures and may potentially reduce production costs per unit of output.

The problem of grass carp disease, however, needs to be addressed through research. In the next phase of the ”Uplands Program”, the diagnosis of grass carp disease(s) and the search for strategies involving its prevention and treatment are planned. Some potential prevention methods have already been described in the previous chapters. Also, some approaches published in literature exhibit some success in the prevention or curing of fish diseases that might also have affected the grass carp in the study area.

A vaccine has been developed for the virus causing haemorrhage disease, which can be easily prepared and is effectively in use in China (Yulin, 2006). Human lactoferrin-transgenic grass carp have shown enhanced resistance to the grass carp haemorrhage virus (Zhong et al., 2002) as well as enhanced immunity to *A. hydrophila* infection (Weifeng et al., 2004). *A. hydrophila* can be treated by controlling the underlying factors (see 7.3.6 and 7.3.7) and use of antibiotics in feed. However, the use of antibiotics is restricted, since fish may develop resistance and, secondly, the diseased fish usually have a lowered appetite, which can hamper the intake of the medications (Jeney and Jeney, 1995). The dietary intake of chitosan enhanced the innate immune system and survivability of common carp when exposed to *A. hydrophila* (Gopalakannan and Arul, 2006) and the lesions of infected common carp can be healed by dipping fish in Neem (*Azadirachta indica*) leaf extract (Harikrishnan et al., 2003). However, the latter method has its restrictions, since manual handling of fish occurs, which may provide additional stress to fish that are already weakened by disease (Harikrishnan et al., 2003). Also, supplementing fish diets with vitamin C showed decreased mortality rates when Mrigal were faced with *A. hydrophila* compared to fish without vitamin supplements (Sobhana et al., 2002).

Once the responsible pathogenic agent has been isolated, some of the above-proposed techniques could be tested to see how effective they are in preventing and/or combating disease in the study area. However, the economic benefit for the farmers also has to be considered and evaluated. Thorarinsson and Powell (2006), for example, recommended evaluating the impact of disease risk, vaccine efficacy and market price on the value of vaccination as a management tool. In addition to the need for further research, more training in basic disease recognition and fish health management should be provided to Vietnamese farmers and extension officers in the future (Van et al., 2002).

Up until now, the local extension service in Yen Chau district has no expertise in the field of aquaculture. Currently, there are not many extension staff members working at the provincial and district levels who are skilled in fish production (Van et al., 2002). The lack of expertise of the local extension service in the field of aquaculture can be explained by the political structure in Vietnam. The National Agricultural Extension Service, established in 1993, is based within the provincial and district offices of the Ministry of Agriculture and Rural Development, while the field of aquaculture is subject to the Ministry of Fisheries, which has no provincial offices of its own (Luu et al., 2002). However, in 2007, the Ministry of Fisheries became a part of the Ministry of Agriculture and Rural Development, so it is hoped that this will also have a positive effect on farmers in remote areas such as Yen Chau.

Also, recently developed strategies and development programs seem to respond to the concerns of local people residing in the mountainous regions. A goal within the SAPA strategy addresses the gap between farmers' needs and the services offered by extension institutions (Luu, 2001a; see 2.2.3). A UNDP (United Nations Development Programme) funded project called "Aquaculture Development in the Northern Uplands" was implemented by the provincial office of the Department of Agriculture and Rural Development in cooperation with the Ministry of Fisheries and FAO. From 1999 to 2002, it has been training farmers from the northern mountainous region in simple aquaculture techniques (Fisheries

Informatics Centre, 2006). According to Edwards (2000), the poor farmers need to be specifically targeted by the national governments with a package of support that includes training, access to micro credits as well as “baskets” of choices from appropriate technologies. Also, increased institutional and infrastructure support for diversification of production and trade should be provided through national policies (Ahmed and Lorica, 2002).

Besides extension services, also hatcheries, fish traders as well as farmers’ unions distribute knowledge and may play an important role in the testing and extension of the above proposed modified aquaculture systems (7.6.1). In the near future, farmers’ unions could organize the purchase of aquaculture inputs that are currently not available in the district but are available in the provincial market. However, it is expected that the district market would rapidly adapt to the higher demand of those products.

Once the local market is saturated with fish from the districts, farmers could extend their markets to other provinces. However, this requires an organized transport of fish with adequate aeration, which currently cannot be managed by the farmers themselves but could be organized by the local traders or farmers’ unions.

8 Conclusion and outlook

Even though the aquaculture yields are currently relatively low, the production of aquatic products is a lucrative business for local farmers and has a strong impact on income generation as well as household protein supply in the region. In the study area, the majority of farmers are involved in the aquaculture venture.

At present, the demands of the local market in Yen Chau cannot be met by the districts' fish production alone. With the recent upgrade of a road that connects the remote area in the north-western mountains with the country's capital Hanoi, lowland fish have started flooding the local markets. In order to keep up with the quickly altering markets in Vietnam, farmers need to increase the outputs of their ponds in order to be sustainable.

The relatively low productivity of the ponds may be explained by various reasons, which include low quality fish seed, poor water quality, poor knowledge in basic aquaculture techniques, low quality of applied feed, low natural food production in the ponds and grass carp disease(s). However, there is potential for the local aquaculture to increase its productivity by overcoming some of the current constraints. Improvements can be reached by simple modifications in fish handling, pond management, adapted species' densities, improved fertilization regimes and adequate feeding as well as better water management. In order for this to happen, an improved system of knowledge exchange is required, e.g. through the local extension service, which in turn requires reform of the political framework aimed at the promotion of small-scale aquaculture in remote areas. Furthermore, an expanded gene pool and better management in the local hatcheries is needed, which should also be addressed at the policy level. In order to overcome other constraints such as getting the frequently occurring grass carp disease(s) under control and formulating a locally producible fish feed, scientific support is required.

Disease of grass carp is probably the most critical restriction in this grass carp-dominated aquaculture system. Within the framework of the "Uplands Program" further research aimed at its diagnosis and prevention as well as treatment will be undertaken. In addition, an improved aquaculture system that is based predominantly on modified water management as well as supplementary feed based on locally available ingredients will be tested in close collaboration with local farmers.

It is expected that the modified aquaculture system may significantly enhance the fish production and thereby increase farmers' income generation as well as home consumption of aquatic resources. Also, a diversification of pond production systems and flexible adjustments to market changes must be considered for future implementation.

Vietnam is a very dynamic country and the inhabitants need to quickly and flexibly adapt to frequently changing markets. This is especially true for Yen Chau farmers, who will probably be forced to change their production patterns in the near future. Prices for maize and cassava, which are currently the most important products for income generation, are likely to be exposed to highly fluctuating markets with Vietnams' heightened presence in the world market as a result of joining the WTO in 2007. Currently, aquaculture in the local farm systems is only a minor component, but it can become more dominant with greater farm specialisation and market orientation. Ethnic minorities such as the Black Thai living in remote areas are among the poorest population groups in Vietnam. Fish is a relatively high-valued product and intensification of fish production could allow these local farmers to participate in the value-adding process and prevent them from being left behind in the overall economic development of the country.

9 Abstract

Son La province is located in mountainous north-western Vietnam and belongs to the poorest regions of the country. In the valleys of this province, fish farming is one of the major activities among farmers who belong to the ethnic Black Thai minority. Up until now, the aquaculture system practiced here has not been scientifically investigated. There is generally very little data available regarding the aquaculture of resource-poor farmers in Southeast Asia. This lack of information can be partly explained by the difficulty in obtaining this data. However, a solid understanding of current aquaculture systems is necessary for any kind of future involvement.

Within the course of a special research program (SFG 564), aquaculture practices in three communes of Yen Chau district (Son La province) were surveyed from January 2004 to June 2006. The research was conducted in a holistic way in order to obtain a detailed description of the typical local aquaculture system with its potentials and limitations. In addition, measures for improvement were developed, which will be tested during the next phase of the special research program.

The data was collected and analyzed on three different levels. On the "macro level", general data is presented regarding the land use and irrigation system in the studied area. Data on the "meso level" concerns the aquaculture and agriculture system and was predominantly collected through interviews with 155 farmers, 22 village headmen and other stakeholders (e.g. hatchery operators). On the "micro level", an in-depth investigation based on measurements and close observation of six individually selected case study farms is presented. This data includes the limnological pond conditions, stocking densities, fish growth rates, food conversion and the profitability of the aquaculture system. The data gathered during these investigations compensates for the information that could not be satisfactorily gathered through the interviews alone.

Currently, around 63% of the households in the study area produce fish in ponds. The aquaculture production is closely linked with other farming activities and is integrated into the overall irrigation system. Farmers stock different carp and tilapia in polyculture with the main species being grass carp. Fish are mainly fed leaves and by-products of crop production, weeds and manure, e.g. from buffalo. The pond system is feed-based and exhibits a more or less continuous water flow; both of these features are rather atypical for small-scale aquaculture.

In the case study farms, the average fish stocking density was 1.0 fish m^{-2}. Calculated based on one hectare, the average daily feed application was 37.1 kg dry matter (DM) and the

annual net production of aquatic species 1.5 tons ha^{-1}, of which roughly 2/3 were sold. The average conversion of feed (DM) to aquatic species biomass was 7.7:1, and the conversion of added nitrogen (feed and manure) to produced nitrogen (aquatic species) was 14.7%.

The yields in the presented system are relatively low compared to other feed-based aquaculture systems. Nevertheless, it has been shown that aquaculture production contributes significantly to food security, generates income and plays a significant role in farmers' lives.

At present, the local market in Yen Chau cannot be completely satisfied by the districts' fish production alone. Recently, a road was upgraded that connects the north-western mountains with the country's capital Hanoi. As a result, fish from the more intensive aquaculture in the lowlands, which are more economically developed than the mountainous region, has started to flood the local markets. This development is expected to proceed, which will leave farmers unable to compete in the market in the future. In order to produce fish in a sustainable way, the current system must be improved so that the local fish production increases.

There are various reasons that can explain the relatively low productivity in the ponds. These include unclassifiable grass carp disease(s) that lead to high mortalities, poor water quality, low fish growth rates caused by low quality of fish seed, low quality of feed and manure applied as well as low natural food availability in the ponds. Furthermore, farmers seem to have limited knowledge regarding basic aquaculture techniques, which may be explained by the lack of training or extension services available in this field.

In the present study, a "basket" of modification measures have been proposed. These measures concern the farms themselves (e.g. the application of improved pond management and use of paddy fields for nursing fish), the institutional and political framework (e.g. the training of farmers and support of the local hatcheries) as well as the research. The focus of the next part of the special research program will be the identification of the causative agents of the grass carp disease(s) and the development of prevention and treatment strategies. Additionally, a modified watering and feeding management system will be tested scientifically. It is expected that this locally adapted, improved aquaculture system will lead to significantly higher fish production.

10 Zusammenfassung

Die Provinz Son La in den Bergregionen Nordvietnams gehört zu den ärmsten Gebieten des Landes. In den dortigen Tälern lebt die ethnische Minderheit Black Thai, zu deren Hauptaktivitäten die Aquakultur zählt. Das praktizierte Aquakultursystem wurde bisher noch nicht wissenschaftlich beschrieben. Über Aquakultur von ressourcenarmen Bauern in Südostasien gibt es allgemein wenige Daten, was u.a. daran liegt, dass diese Daten sehr schwierig zu erfassen sind. Eine genaue Kenntnis der jetzigen Systeme ist aber unumgänglich für jegliche zukünftige Interventionen.

Von Januar 2004 bis Juni 2006 wurde im Rahmen des Sonderforschungsbereichs (SFB) 564 eine holistische Untersuchung des Aquakultursystems in drei Kommunen des Distrikts Yen Chau der oben genannten Provinz durchgeführt. Hierbei wurde das gegenwärtige System mit seinen Grenzen und Potenzialen erfasst, als Grundlage zur Entwicklung nachhaltiger Verbesserungsmaßnahmen, die dann im nächsten Schritt des Forschungsvorhabens getestet werden sollen.

Die Datensammlung fand auf drei Ebenen statt: auf der „Makroebene" wurden Daten zur allgemeinen Landnutzung und zum Bewässerungssystem erhoben. Daten auf der „Mesoebene" betreffen das Teich- und landwirtschaftliche System und beruhen hauptsächlich auf Interviews mit 155 Bauern, 22 Dorfoberhäuptern und anderen Akteuren (z.B. Betreiber von Fischbrutstationen). Auf der „Mikroebene" wurden Messungen und Beobachtungen anhand von sechs Fallbeispielen durchgeführt. Diese Daten wurden benötigt, um quantitative Daten zu ergänzen, die auf der „Mesoebene" nicht zufrieden stellend zu erfassen waren. Sie umfassen u.a. die limnologischen Teichbedingungen, Bestandsdichten, Fischwachstumsraten, Futterverwertung, Erträge und auch die Wirtschaftlichkeit der Fischproduktion.

Derzeit werden in den meisten Haushalten der Untersuchungsregion Fische in Teichen produziert. Die Teichproduktion ist eng mit anderen landwirtschaftlichen Aktivitäten verknüpft und in das allgemeine Bewässerungssystem integriert. Die Bauern besetzen ihre Teiche mit verschiedenen Karpfen und Tilapien in Polykultur, wovon der Graskarpfen den größten Anteil ausmacht. Die eingesetzten Fischfuttermittel bestehen überwiegend aus Blättern und Nebenprodukten der Pflanzenproduktion, Unkräutern und organischen Düngern, v.a. Büffelkot. Dieses Teichsystem ist futterbasiert und weist einen mehr oder weniger kontinuierlichen Wasserdurchfluss auf, beide Merkmale sind eher untypisch für kleinbäuerliche Aquakultur.

In den Fallbeispielen lag die durchschnittliche Fischbestandsdichte bei 1 Fisch pro m^2. Auf einen Hektar bezogen, wurden im Durchschnitt täglich 37,1 kg Futter und Dünger (in

Trockenmasse, TM) appliziert und die durchschnittliche jährliche Nettoproduktion von aquatischen Produkten betrug 1,5 Tonnen, wovon ca. 2/3 verkauft wurde. Im Durchschnitt lag die Umwandlung von Futter (TM) zu Fischbiomasse bei 7,7:1 und von eingesetztem Stickstoff (Futter und Dünger) zu produziertem Stickstoff (aquatische Produkte) bei 14,7%.

Die Erträge in diesem System sind gering im Vergleich mit anderen futterbasierten Aquakultursystemen. Trotzdem konnte gezeigt werden, dass die derzeitige Fischproduktion entscheidend zum Haushaltseinkommen und zur Nahrungsmittelsicherung der Bauern beiträgt.

Der Fischbedarf auf den Distriktmärkten kann derzeit jedoch nicht alleine durch die regionale Aquakulturproduktion gedeckt werden. Mit dem Ausbau einer Strasse, welche die abgeschiedene Bergregion mit der Hauptstadt Hanoi verbindet und damit den Fischtransfer begünstigt, werden seit kurzem Fische aus dem ökonomisch weiter entwickelten Tiefland importiert. Es wird erwartet, dass diese Entwicklung weiter voranschreiten wird und lokale Bauern auf längere Sicht nicht mehr konkurrenzfähig sein werden. Damit die Bauern auf nachhaltige Weise Fische produzieren können, muss das gegenwärtige System verbessert werden um die lokale Fischproduktion zu steigern.

Für die derzeit geringen Erträge gibt es eine Reihe von Gründen, wie z.B. häufig vorkommende, bislang nicht identifizierte, Graskarpfenkrankheit(en) verbunden mit hohen Mortalitäten, geringe Wasserqualität, geringe Fischwachstumsraten, die auf einer geringen Qualität der Fische aus den lokalen Brutstationen, geringer Qualität der applizierten Futtermittel und auf einer geringen Verfügbarkeit von Naturfutter beruht, sowie fehlende Beratung und damit verbunden mangelndes Basiswissen im Bereich der Aquakultur.

Es wurde eine Reihe von Verbesserungsmaßnahmen vorgeschlagen, die die landwirtschaftlichen Betriebe (z.B. ein modifiziertes Teichmanagement, Nutzung von Reisfeldern für die Fischaufzucht), das institutionelle und politische Rahmenwerk (z.B. Training für die Bauern, Förderung der lokalen Brutstationen), sowie die Forschung betreffen. Ein Forschungsschwerpunkt in der nächsten Phase des SFB ist die Identifizierung des/der Erreger der Graskarpfenkrankheit(en) und das Auffinden möglicher Wege zur Krankheitsvorsorge und -bekämpfung. Außerdem wird ein in dieser Phase entwickeltes verbessertes Wasser- und Fütterungsmanagement wissenschaftlich getestet. Es wird erwartet, dass dieses an die lokalen Gegebenheiten angepasste Aquakultursystem zu signifikant höherer Fischproduktion führen wird.

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12 Appendix

Photos of ponds and aquaculture practices in the study area




Typical feeding practices




Harvest of fish for sale

Harvest of small aquatic products

Harvest of fish for household consumption

The Uplands Program

Research for Sustainable Land Use and Rural Development in Mountainous Regions of Southeast Asia
Funded by DFG

QUESTIONNAIRE FOR FISH FARMERS

Date and time of interview: ____/____/2005 ____:____ a.m./p.m.

Name of respondent: ____

Age and sex **Age:** ___________ **years** **male** ☐ **female** ☐

Name of household head: ____

Household members: **Total** ___________**; of which:** _______**adults** _______ **children**

Ethnic group: ____

Village: ____

Commune: ____

I. GENERAL FARM INFORMATION

1. What is the size of your entire farm? ____________ m^2

2. Which crops do you produce on your farm? How big is the area dedicated to each crop?
a) ________________(crop) ____________ m^2
b) ________________(crop) ____________ m^2
c) ________________(crop) ____________ m^2
d) ________________(crop) ____________ m^2
e) ________________(crop) ____________ m^2
f) ________________(crop) ____________ m^2
g) ________________(crop) ____________ m^2

3. Which and how many of each animal do you raise on your farm?
Buffalo ____________, Cattle ____________, Pigs ____________, Goats ____________, Chickens ____________, Ducks ____________, Other(s) _____________ (Other(s): ____________)

4. Which is the most important product for income generation?
Most important: _____________________, followed by _____________________ , followed by ____________________

5. Which is the most important product for household consumption?
Most important: _____________________, followed by ______________________, followed by ____________________

6. How much was your total household income in the last year? _________________ VND

7. How much was your total income in the last year that came from farm activities? _________________ VND

8. How much was your total income in the last year only from fish production? _________________ VND

9. How much was the total income in the last year that was earned from other sources? _________________ VND
Which source(s)? ____

10. Do individuals in your household work off-farm? Yes ☐ No ☐**, if yes, who?** ___________________ **In total, approximately how many days does he/she work per year?** ______________________ **How much does he/she earn from one work day?** ______________________ VND

11. Are there regularly off-farm jobs available in your region? Yes ☐ No ☐ **Would a member in your household be able to work off-farm whenever she/he has time?** Yes ☐ No ☐ **If no, how often would he/she work if had the chance to get a job?** ______________________________

II. GENERAL POND DESCRIPTION AND USE OF WATER

1. How many ponds do you own? ____________ **ponds**

2. How big are the respective ponds (in m^2)**?** A: _______ B: _______ C: _______

3. Please describe the location of your pond. A: _______ B: _______ C: _______
(1 = residential area, 2 = paddy field area, 3 = upland field area, 4 = other(s); other(s): ________________)

4. What are the respective ponds used for? A: _______ B: _______ C: _______
(1 = grow-out, 2 = nursery, 3 = other(s); other(s): _______________________)

5. When did you build the respective pond (year)? A: _______ B: _______ C: _______

6. What was the purpose of building the respective water body? A: _______ B: _______ C: _______
(1 = fish production, 2 = water reservoir, 3 = other(s); other(s): _______________________)

7. Is the pond area mentioned in the Red Book? Yes ☐ No ☐ **If yes, since when?** ______________________________

8. Is the respective pond used during the whole year or only during the rainy season? A: _______ B: ______ C: ______
(1 = whole year, 2 = only during rainy season, 3 = other(s); other(s): _______________________)

9. Where does the water come from in the respective pond? A: _______ B: _______ C: _______
(1 = Chieng Khoi Lake, 2 = spring, 3 = precipitation, 4 =stream 5= other(s); other(s): _____________________)

10. Is there water flowing through your pond? Yes ☐ No ☐ **If yes, during approximately how many months per year do you have water flow?** A: ______ B: ______ C: ______

11. Does the water flow through other ponds or paddy fields before entering the respective pond?
A: ______ B: ______ C: ______
(1 = paddy fields, 2 = ponds, 3 = no flow through previous fields/ponds, 4 = other(s): _____________________)

12. Where does the pond water flow out to? A: _______ B: _______ C: _______
(1 = paddy fields, 2 = other fields, 3 = other ponds, 4 = canal, 5 = stream, 6 = other(s); other(s):___________________)

13. Do you think there is a difference in the water quality between different water sources? Yes ☐ No ☐ **If yes, which water source do you consider to be the best for fishponds? Why?**
____
____

14. Do you think there is an impact when water flows through crop fields, e.g. paddy plots, before entering your pond? Why? Do you think it has a good or bad impact?
____
____

15. Do you think there is an impact when water flows through other ponds before entering your pond? Why? Do you think it has a good or bad impact?
____
____

16. Do you think there is an impact when water flows from the ponds into paddy fields afterwards? Why? Do you think it has a good or bad impact?
____
____

17. What do you consider to be more productive – ponds with continuous water flow or closed pond systems? Why?
____
____

18. Do you use pesticides? Yes ☐ No ☐ **If yes, how often?** ____________ **Which are typical pesticides that you use**?
____

19. Have you ever heard about IPM? Yes ☐ No ☐ **If yes, from where?** ____
And do you practice IPM? Yes ☐ No ☐ **If yes, since when?** ___________________

20. Do you use pond water for the following purposes?
(1 = often, 2 = sometimes, 3 = seldom, 4 = never)

Taking baths ______ **If yes, how would you estimate the impact of this action on your pond?** __________
(1 = good, 2 = bad, 3 = no impact, 4 = no opinion)
Washing clothes ______ **If yes, how would you estimate the impact of this action on your pond?** __________
(1 = good, 2 = bad, 3 = no impact, 4 = no opinion)
Irrigation of garden ______
Washing vegetables ______
Cooking ______
Other(s) ______ **Which?** ____

21. Do you sometimes have to cope with water shortages? Yes ☐ No ☐ **If yes, in which months?** __________________
Does it have a negative impact on your fish? Yes ☐ No ☐ **If yes, why?**___________________

22. Have you ever lost fish in the winter due to very low water temperatures? A: _______ B: _______ C: _______
(1 = often, 2 = sometimes, 3 = seldom, 4 = never); **if yes: which fish species have been killed (please rank)?**
____

23. Have you had to cope with flooding in the past several years? Yes ☐ No ☐ **If yes, in which years?** _____________
What happened to your fish at that time? ____________________________

24. Are you able to drain the respective pond? A: _______ B: _______ C: _______
***I*f yes, does draining depend on other farming activities?** A: _______ B: _______ C: _______
(1 = Yes 2 = No)

25. Do you dry-out the pond before stocking? A: _______ B: _______ C: _______
(1 = yes, always, 2 = yes, often, 3 = yes, sometimes, 4 = never, 5 = other(s); other(s): _____________________________)

26. Do you remove the pond mud? A: _______ B: _______ C: _______
(1 = yes, always, 2 = yes, often, 3 = yes, sometimes, 4 = never, 5 = other(s); other(s): _____________________________)
If yes, what do you do with the pond mud? ____

III. STOCKING OF POND

1. When did you stock the respective pond? A: ____/____ B: ____/____ C: ____/____
(Month and year)

2. Which fish species did you stock (number, weight, price, fish source)?

Pond A:

Fish species	Number of fish	Average individual fish weight at stocking (g)	Price (VND kg^{-1})	Source of fish

Pond B:

Fish species	Number of fish	Average individual fish weight at stocking (g)	Price (VND kg^{-1})	Source of fish

Pond C:

Fish species	Number of fish	Average individual fish weight at stocking (g)	Price (VND kg^{-1})	Source of fish

3. How were the fish transported from the place of purchase to your farm? ___________________________________

4. How do you estimate the quality of fish from the hatcheries in Son La and Yen Chau respectively? Why?
____
____

5. Do you also stock non-fish aquatic products (e.g. shrimps, snails etc.) in your pond? Yes ☐ No ☐ **If yes, what?**
____

IV. FEED MANAGEMENT

1. What do you usually feed to your fish in your grow-out pond?
____
____

2. How often do you feed the following items?
(1 = often, 2 = sometimes, 3 = seldom, 4 = never)

Banana leaves _____
Cassava leaves _____
Maize leaves _____
Bamboo leaves _____
Grass _____ **What are typical grasses that you use as feed?** ________________________
Where do you usually collect the grasses? ___________________________
Rice bran _____
Maize meal _____
Cassava meal _____
Duckweed (*Lemna*) _____
Other aquatic plants _____
Sweet potato leaves _____
Mulberry leaves _____
Residues from liquor preparation _____
Cassava tubers _____
Cassava peel _____
Kitchen waste _____
Vegetables _____ **Which?** ____
Other _____ **What?** ____
Other _____ **What?** ____

3. Are there differences in feeding practices between the different ponds? Yes ☐ No ☐ If yes, which?
____
____

4. In the case that you have a nursery pond, what do you feed to your fish in the nursery pond?
____
____

5. Do you sometimes face shortages in feed availability? Yes ☐ No ☐ **If yes, when do you face this problem?**
____

6. Have you ever purchased additional feed for fish? Yes ☐ No ☐ **If yes, what kind of feed?** _____________________
Why did you buy additional feed? ___________________________ __________________ **How much have you bought during the last year?** ____________________________ **How much did you pay for it?** __________ VND

7. Is there any plant that you cultivate exclusively for feeding your fish? Yes ☐ No ☐ **If yes, what?**
_________________________ **How much do you produce of it?** *(area or yields)* _______________________________

8. Is there sometimes competition between the animals in the case of limited feed? Yes ☐ No ☐ **If yes, between which animals? ________________________________ Which animals usually get priority? __________________________**
Why?____

9. Do you think that all fish species in your pond have enough feed? Yes ☐ No ☐ **If no, which fish might not have enough feed? Why? ____**

10. What do you think the following fish species feed on in the ponds?
Grass carp: ____
Mud carp: ____
Common carp: ____
Silver carp: ____
Silver barb: ____
Tilapia: ____

V. MANURE MANAGEMENT

1. Do you use manure in your ponds? Yes ☐ No ☐ **If yes, which ponds? _____________**

2. What kinds of manure do you usually use? ____/____/____
(1 = buffalo, 2 = cattle, 3 = pig, 4 = chicken, 5 = green manure, 6 = nightsoil, 7 = other(s); other(s): ________________)

3. What do you use nightsoil for? ____

4. Please estimate the amount and frequency of manure application. A: ____/____ B: ____/____ C: ____/____
(e.g. 3 kg / twice a week)

5. How do you decide how much and when to supply manure to your pond? ___________________________________

6. In which form do you usually supply manure? ______
(1 = fresh, 2 = dried, 3 = processed, 4 = other(s); other(s): ____)

7. Have you placed animals directly next to or above the pond so that droppings immediately enter your pond?
Yes ☐ No ☐ **If yes, in which pond? ______________ Please describe:** ____

8. Do you use green manure? Yes ☐ No ☐ **If yes, which? ____**

VI. HARVEST AND YIELDS

1. When was the last time that you harvested the respective pond? A: ____/____ B: ____/____ C: ____/____
(month/year)

2. When did you stock the pond that you harvested the last time? A: ____/____ B: ____/____ C: ____/____
(month/year)

3. How many kg of total fish did you harvest the last time? A: ______ B: ______ C: ______

4. How many VND did you earn from your last fish harvest? A: ______ B: ______ C: ______

5. Did you harvest all fish or big fish only? A: ______ B: ______ C: ______
(1 = all fish, 2 = only big fish, 3 = other(s); other(s): _______________________)

6. When do you usually decide to sell fish? ______
(1 = when money is needed, 2 = when fish are big, 3 = other(s); other(s): _______________________)

7. How many fish and kg of each fish species did you harvest? What were the prices of those fish?

Pond A:

Fish species	Number of fish	Average individual harvest weight of fish (g)	Total weight per species (kg)	Use of produce (e.g. household consumption)	Point of sale	Price (VND kg^{-1})

Pond B:

Fish species	Number of fish	Average individual harvest weight of fish (g)	Total weight per species (kg)	Use of produce (e.g. household consumption)	Point of sale	Price (VND kg^{-1})

Pond C:

Fish species	Number of fish	Average individual harvest weight of fish (g)	Total weight per species (kg)	Use of produce (e.g. household consumption)	Point of sale	Price (VND kg^{-1})

8. Can you estimate what percentage of your total fish production from one production cycle you usually sell? ______

9. How many kg of fish do you usually harvest per month for sale? A: ______ B: ______ C: ______

10. How many kg of fish do you usually harvest per month for household consumption?
A: ______ B: ______ C: ______

11. What are your reasons for growing fish? A: ______ B: ______ C: ______
(Several answers possible: 1 = take advantage of body of water; 2 = improve income; 3 = food security; 4 = job creation; 5 = other(s); other(s): ________________________)

12. What is more important for you: having fish for getting cash income or for home consumption? Why?
____
____

13. Do you sometimes process your fish? Yes ☐ No ☐ **If yes, how do you process the fish?** ________________________
What is the purpose? ________________________________ **What are the processed fish used for?** ________________

14. Do you usually have problems with theft? Yes ☐ No ☐ **If yes, in which pond(s)?** _________ **Could you estimate how many fish you have lost from theft in the last year?** ___________ kg

15. Which non-stocked products do you harvest from your pond?
(1 = often, 2 = seldom, 3 = never)

Shrimp ______
Mussels ______
Snails ______
Crabs ______
Non-stocked fish species ______ **Which?** ________________________________
Algae ______
Other(s) ______ **Which**? ________________________________

16. Can you estimate how many kg of those by-products you harvest from the respective pond during one production cycle? A: ______ B: ______ C: ______

17. Can you estimate how many kg of those by-products you harvest from your paddy fields during one year? ___________

18. What do you usually use those by-products for? ______
(1 = home consumption, 2 = selling, 3 = home consumption + selling, 4 = other(s); other(s): ______________)

19. How would you rank the tastes of different fish species in your pond?
(Start with the fish species that is considered to be the most delicious one)
_______________________>_______________________>_______________________>_______________________

20. Can you estimate how many kg of each of the following animal products your household consumes per month?

Poultry meat	______ kg
Other meat sources (e.g. buffalo, beef, pork, etc.)	______ kg
Eggs	______ eggs
Fish	______ kg
Other aquatic animals (e.g. snails, mussels…)	______ kg
Insects, worms (e.g. silkworms), etc.	______ kg
Milk and milk products	______ kg
Other(s): ______________________________	______ kg

VII. POND INPUTS

1. **Have you invested time into pond preparation or restoration during the last production cycle?** Yes ☐ No ☐
If yes, for which pond(s)? _______________ **How many days?** _______________ (per pond)

2. **Have you ever invested money** (VND) **into the preparation or restoration of your ponds?** Yes ☐ No ☐
If yes, for which pond? __________ **What for?** ____________________**How much did you pay?** ____________ VND

3. **Do you have fishing nets?** Yes ☐ No ☐ **If yes, which nets?** a)_____________________ b)______________________ c)________________ **When did you buy them?** a)__________ b)__________ c)__________**How much did you pay for it/them** (VND)**?** a)_________________, b)________________, c) _________________

4. **Have you bought any pond inputs (e.g. lime, inorganic fertilizer) during the last production cycle?** Yes ☐ No ☐
If yes, what did you buy? __________________________ **For which pond(s)?** _______________ **How much did you pay for it** (VND)**?** _______________

5. **Do you have access to lime?** Yes ☐ No ☐ **If yes, where do you get it from?** _________________________________

6. **Who in your household usually takes care of the pond(s)?** ____

7. **How many minutes per day does your household generally spend on your pond(s) in the dry season?**
A: ______ B: ______ C: ______

8. **How many minutes per day does your household generally spend on your pond(s) in the rainy season?**
A: ______ B: ______ C: ______

9. **Who usually takes care of the following tasks – men, women and/or children?**

Pond activity	Men	Women	Children
Pond preparation			
Stocking of fish			
Collection and application of feed			
Collection and application of manure			
Harvesting fish for household consumption			
Harvesting fish for sale			
Harvesting snails, shrimp, crabs and mussels			
Sale of fish on the market			
Processing of fish, e.g. cooking			

10. Do you get help from friends and neighbours during working peaks? _______
(1 = always, 3 = sometimes, 3 = never)

11. Have you ever hired labour for pond purposes? Yes ☐ No ☐ **If yes, when?** ________________________________
What for? ____________________________________ **How much did you pay** (VND day^{-1})**?** _________________

VIII. FISH DISEASES

1. Have you ever had to cope with fish diseases in the respective pond? A: _____ B: _____ C: _____
(1 = often, 2 = sometimes, 3 = seldom, 4 = never)
(If yes, please continue with section VIII, otherwise go to section IX)

2. Which fish species were affected? ___________________________ **Do you know the name of the disease?** ____________________________ **Please describe the symptoms:** ______________________________________

3. Since which year have you faced problems with this fish disease? ________

4. Have you had to cope with grass carp disease in the last production cycle? Yes ☐ No ☐ **If yes, in which pond(s)?** ______________ **How many fish have died?** ____________ **What was the approximate weight of dead fish (g)?** _______________

5. Have you taken any action toward curing your fish? Yes ☐ No ☐ **If yes, what did you do?** ____ **Where did you learn of this technique?**____________________
Was it successful? ____

6. Do you have any insight as to why your pond has been affected by fish disease?
____
____

IX. CONSTRAINTS IN FISH PRODUCTION

1. Have you ever attended a training course? Yes ☐ No ☐ **If yes, in which field?** ______________________________

2. Have you ever attended a training course in aquaculture? Yes ☐ No ☐ **If yes, in which field?** ________________________ **Who organized the training?** ____

3. What would you consider to be the biggest problem you face in fish production? ______________________________

4. How do you assess the impact of the following potential problems on your fish production?
(1 = very big problem, 2 = big problem, 3 = minor problem, 4 = no problem, 5 = do not know)

Fish diseases	_____
Lack of extension service/training in the field of aquaculture	_____
Low quality of fish seed	_____
Low water quality	_____
Water shortages	_____
Entry of pesticides	_____
Negative impact of inorganic fertilizers	_____
Lack of access to pond inputs (e.g. lime)	_____
Lack of crop residues	_____
Lack of feed for all fish species in the system	_____
High investment costs for pond preparation	_____
High costs for fish seed	_____
High mortalities caused by long transports	_____
Mortalities caused by low water temperatures	_____
Theft	_____
Natural enemies	_____ **Which?** ________________________
Insufficient land use rights	_____
High time requirements	_____

5. Are there further problems that are not mentioned above? Which? ______________________________________

Workshop in Yen Chau from 17^{th} to 18^{th} of June 2004
"Grass carp diseases and aquaculture in Yen Chau"
General design, photos and summary of the minutes

Organized and presented by Silke Steinbronn and Rupert Friederichsen

Workshop participants

In total, 40 people: farmers, extension workers and researchers

General design

In total, 4 sessions (a half day each) consisting of group work, presentation of the group work and lectures and discussions

Group work

Participants divided into 4 groups for the group work (2 groups of extension workers, 1 male farmer group, 1 female farmer group), group work was facilitated by 4 trained Vietnamese moderators; visualization of findings on posters



Presentation of group work

A participant from each work group presented the findings on posters


Lecture and Discussion
Lecture and moderated discussion with staff of Research Institute of Aquaculture, Hanoi



Minutes of the workshop

Day 1

Registration, welcome address (Head of Extension Department Yen Chau; Vice Chairman of the People's Committee Yen Chau; Coordinator of the Uplands Program) and introduction of participants; introduction of workshop time schedule and purpose

Session 1
Group work: Description of typical aquaculture systems in Yen Chau; farmers' problems with fish production
Presentation of group work
Lecture and discussion: Overview of aquaculture systems and basic biological processes in the pond; discussion of the findings from the group work

Session 2
Group work: local perceptions of fish disease (symptoms, seasonality and frequency of occurrence) and possible causes of fish disease (two posters are produced: one about the observed fish diseases in Yen Chau, the other one about possible causes)
Presentation of group work
Lecture and discussion: Common fish diseases in pond culture and factors causing the outbreak of fish diseases; discussion of the findings from the group work

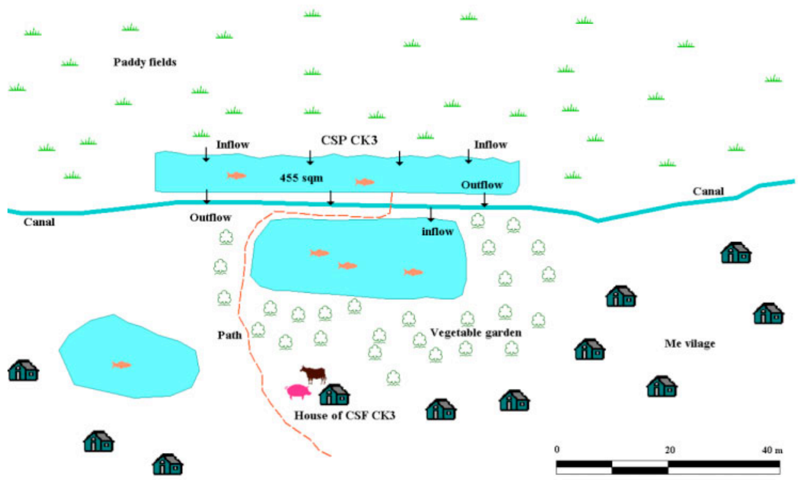
Day 2

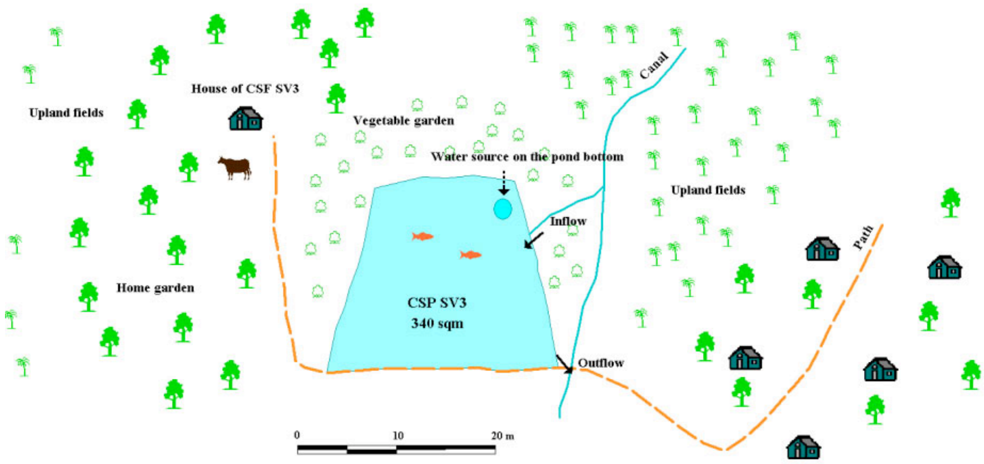
Session 3
Group work: Participants' experiences in combating fish diseases
Presentation of group work
Lecture and discussion: Possible treatments of fish diseases; discussion of the findings from the group work

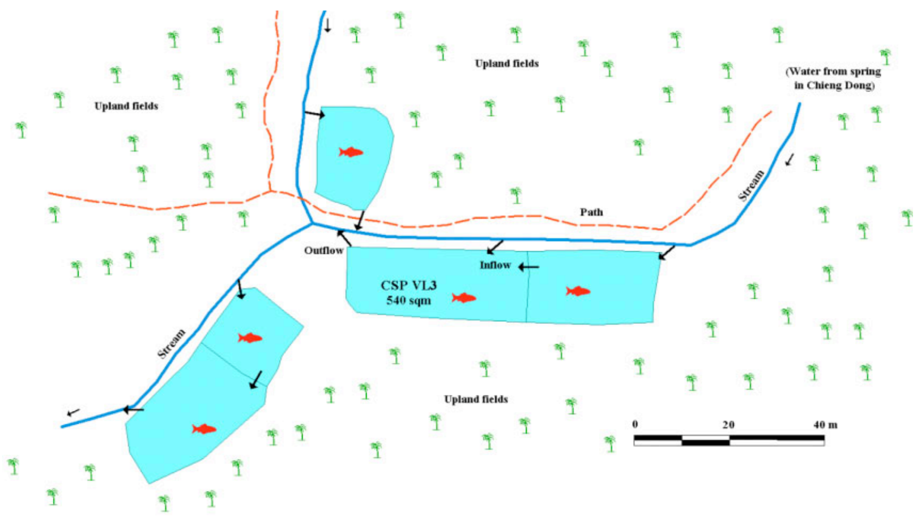
Session 4
Lecture and discussion: Disease prevention measures and general aquaculture techniques
Group work: Applicable prevention measures in Yen Chau (based on the visualized results of group work in session 1: Participants try to find possible solutions for the problems they defined the first day by combining the newly acquired information with the facilities they have)
Presentation of group work and mutual discussion with the researchers

Evaluation of workshop, Closing ceremony

Sketches of the ponds, which are not considered on the micro level (CK3, SV3, VL3)







Division, classes and genera of identified phytoplankton in the case study ponds

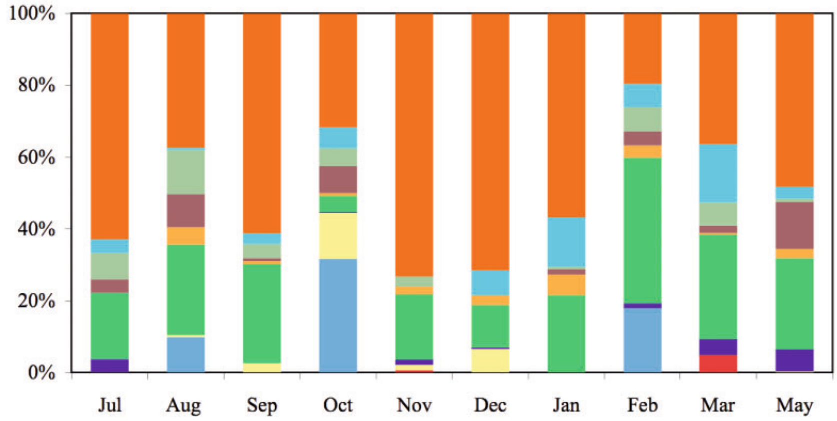
HETEROKONTOPHYTA
Chloromonadophyceae
Goniostomum
Xanthophyceae
Opiocytium
Tribonema
Chrysophyceae
Dinobryon
Bacillariophyceae
Caloneis
Climacoephenia
Cocconeis
Cyclotella
Frustulia
Gomphonema
Grammatophora
Gyrosigma
Lauderia
Licmophora
Melosira
Navicula
Neidium
Nitzschia
Pinnularia
Rhizosolenia
Rhopalodia
Surirella
Synedra
CHLOROPHYTA
Chlorophyceae
Actinastrum
Ankistrodesmus
Borodinella
Characium
Chlamydomonas
Chlorella
Chlorococcum
Chodatella
Coelastrum
Coenochloris
Coenococcus
Coenocystis
Crucigenia
Dictiochlorella
Dictyococcus
Dictyosphaerium
Dispora
Franceia
Golenkiniopsis
Gonium
Heleococcus
Hyaloraphidium
Kirchneriella
Korschikoviella
Largerheimia
Lauterborniella
Micractinium
Nephrochlamys
Oocystidium
Oocystis
Palmella
Pandorina
Pediastrum
Planctococcus
Protococcus
Scenedesmus
Schizochlamydella
Schroederia
Schroederiella
Sphaerocystis
Tetraedron
Tetrastrum
Treubaria
Trochiscia
Ulothrix
Westella
Zygnematophyceae
Closterium
Cosmarium
Cylindrocystis
Euastrum
Gonatozygon
Hyalotheka
Netrium
Staurastrum
CYANOPHYTA
Cyanophyceae
Coccogoneae
Aphanocapsa
Aphanothece
Coelosphaerium
Chroococcus
Dactylococcopsis
Gloeocapsa
Merismopedia
Microcystis
Synechococcus
Hormogoneae
Anabaena
Anabaenopsis
Aphanizomenon
Eucapsis
Hapalosiphon
Lyngbya
Merismopedia
Oscillatoria
Phormidium
Pseudoanabaena
Spriulina
Tolypothrix
DINOPHYTA
Dinophyceae
Ceratium
Glenodinium
Gymnodinium
Peridinium
EUGLENOPHYTA
Euglenophyceae
Euglena
Lepociniclis
Phacus
Strombomonas
Trachelomonas
RHODOPHYTA
Rhodophyceae
Florideophycidae
Lemanea

Genera of identified zooplankton in the case study ponds

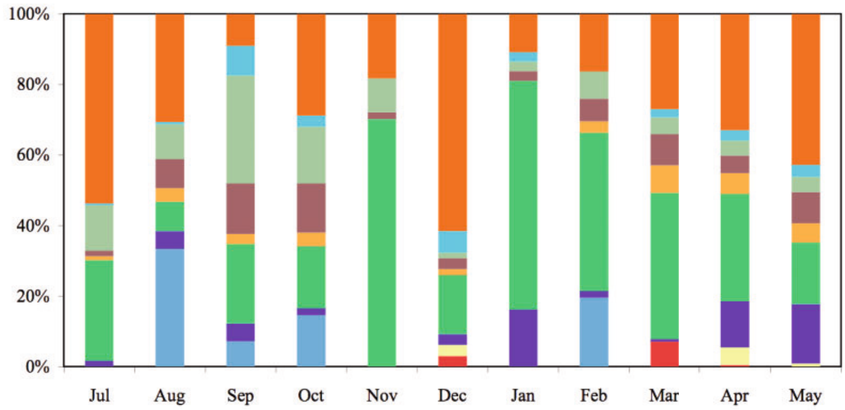
Nauplius
Copepoda
Copepodid
Mesocyclops
Mongolodiaptomus
Sinocalanus
Thermocyclops
Cladocera
Bosminopsis
Ceriodiaphanosoma
Diaphanosoma
Moina
Rotifera
Asplanchna
Brachionus
Filinia
Hexarthra
Keratella
Lecane
Polyarthra
Tetramastix
Trichocera

Proportions of phytoplankton classes of total phytoplankton counts in three selected case study ponds

a) Pond CK2



b) Pond SV1



c) Pond VL1