Framework for feasibility studies written by HAKI

Gergő Gyalog – András Péteri

National Agriculture Research and Innovation Centre, Research Institute for Fisheries and Aquaculture

Szarvas

February, 2016

Introduction

NARIC HAKI has longstanding experience in extension toward aquaculture farmers of the region, but these contacts with the industry were not commercialized enough to provide a strong source of institute funding. To improve the effectiveness of market-based industrial connections, it is worth boxing up our knowledge into "service packages" and follow certain pricing strategies on the extension market.

One type of market-based industrial relationships is when a potential investor in aquaculture requires some basic technical/biological/technological knowledge how to build up and operate a fish production system. Extension centers usually prepare feasibility studies to meet this need in a formulated manner. By writing this deliverable, we intend to outline the content of such a feasibility study so that later on it can serve as a reference when we receive an enquiry from the industry.

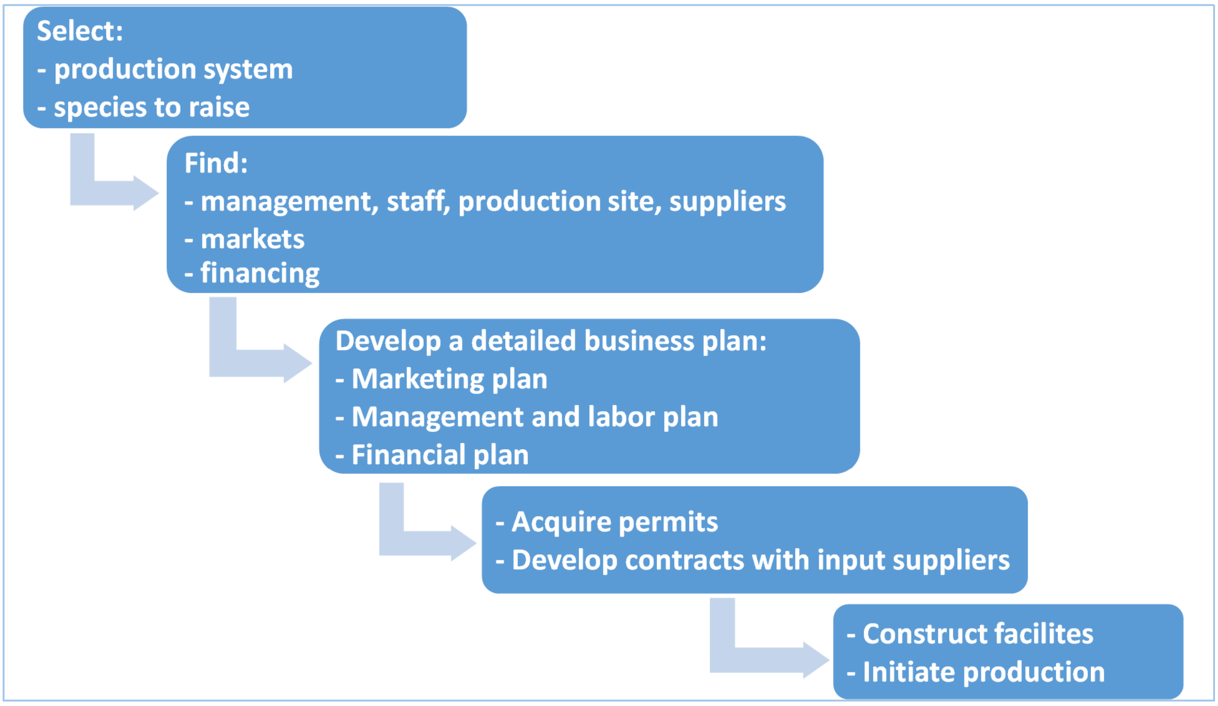
The deliverable consists of two parts:

- Part A provides a theoretical framework feasibility studies. This section outlines (i) what knowledge is needed by potential investors in aquaculture and (ii) considers those steps of analysis and study writing that are supposed to answer these needs. Part A (with Annex I) also considers factors to evaluate so that potential investors can be oriented before writing a feasibility study.
- Part B is presented as an example for feasibility studies, answering the needs of hypothetical investor in Recirculation Aquaculture System used for African catfish farming, as the most comment subject of aquaculture investment nowadays in Central Europe.

Part A

1. The scope and content of a feasibility study

To start an aquaculture business various steps are needed to be taken. Engle (2010)[1] summarized these steps as presented by the graph below.



I. **Identification of production system** used for production and **selection of species** to produce are key steps with long-lasting effects in business start-up process. However, most of the time client investors looking for expertise from NARIC HAKI are determined to produce a certain species or build a certain kind of farming system. The reason for being keen on a certain kind of species/system usually originates either (i) from emotions attached to fish/aquaculture or (ii) possessed expertise/resource/market based on which a technology is predestined. If the latter is the case then there is no need for further consideration of this step. However, if the potential investor does not know which species/system to choose or doesn't have objective justification behind the favored one, a through consideration of these critical elements are need. To answer the questions '*which species to produce?*' and '*which production system/technology to be used for production?*' it is critical to assess the strengths and weaknesses both at the production and the market side. The following points are worth being considered:

Market side:

- What is the overall demand for fish and how it evolves over time in the country?
- What are the major species consumed in the country, what are the emerging species?
- What are the main distribution channels in the fish market? (selling on-farm, trough wholesalers, catering, direct selling to retails chains, specialized fish shops)

[1] Engle, C.R. 2010. Aquaculture economics and financing: management and analysis. Wiley-Blackwell, Ames, Iowa.

- How fish is marketed in terms of degree of processing? (live, fresh, primary processed form, filleted, ready-to-kitchen form)
- What product differentiation strategies exist?

Production side:

- What resources are available abundantly in the region/country and what are the comparative advantages of the geographical region? What are the price levels for water, land, feed, aquaculture machinery, labour? Based on relative resource endowments recommendations can be made with regard to production system and technology to be used (Annex I. provides a conceptual framework to evaluate comparative advantages)
- Are there suppliers of seed, feed and aq. equipment within reasonable distance?
- What are the skills and knowledge of the investor related to fish farming technologies?

As most of these factors cannot be quantified, there is no any predictive modelling framework that can be used to select the best species and technology. Instead of this, an iterative discussion should be performed in between the NARIC HAKI and the client. Thus this process is outside the scope of a feasibility study and restricted to an informal discussion.

II. Once the species and farming system are identified for the investment, the next step is to assess the resources (management, staff and capital) needed for the production. **Feasibility studies** written by NARIC-HAKI are intended to provide information to the investor based on which he can decide whether he wants to proceed with the investment, and he can **assess the level of management skill, workforce, capital and demand** required to successfully start up and operate the business. Having these factors assessed he can start finding markets, financing, input suppliers, staff and site for production. The feasibility study can also serve as a starting point to develop a detailed business plan required by banks providing the loan.

The detailed objectives of a feasibility study are:

a) To present **engineering plans** for one or more different sizes of the selected production system (technical conceptual plans). This engineering plan helps to (i) understand how much investment capital is required and (ii) to assess the skill needed to manage a system described. If engineering plans are developed for more (2 or 3) sizes, economies/diseconomies of scope can be assessed, based on which the optimal size of a business can be recommended.
b) To describe a bio-plan into the previously described systems optimized to the exact species selected. This bio-plan consists of a (i) stocking and biomass management plan, (ii) a described feeding regime, and (iii) estimated growth patterns both for individuals and for the entire biomass. This section helps to understand what level of working capital is required and to assess the number of workforce needed for operation.
c) To conduct economic analysis with certain assumptions regarding output and input market prices. Economic analysis contains cost benefit analysis using NPVs and enterprise budgets and also sensitivity analysis with respect to FCR and market prices.

Part B

A study on the technical and economic feasibility of African catfish production in Recirculating Aquaculture System in Hungary

General background

Central European aquaculture has been stagnating for a while in terms of total production volume, but there has been changes with respect to fall and rise of produced species, investment into new systems etc. If we look at the species-group level it can be seen that production growth in the last ten years (2003-13) in our region occurred mainly for catfish and sturgeon production (data encompasses production of HU, RO, SI, SK, CZ, HR, AT, DE, PL, BG, LT, LV, EE, BY, MD, SRB, BIH).

Species groups	2003 production (t)	2003 production (t)	% change
carps	94,545	105,668	+12%
salmonids	45,269	38,562	-15%
catfish	1,752	4,783	+173%
sturgeons	316	1,378	+336%

As development of catfish aquaculture (including Silurid, Clarid and Ictalurid species) is more highlighted topic in Hungary and neighboring countries, we decided to elaborate feasibility studies for African catfish farming in Recirculating Aquaculture Systems.

African catfish is an air-breathing species and this biological feature allows it to tolerate high biomass density (up to 500 kg/m^3), since it doesn't need oxygen in the water and it doesn't demand good water quality. This makes African catfish an ideal subject of capital intensive aquaculture investments, as high maximum allowable biomass density helps to spread the large investment costs over a high production. Despite the fact that Recirculating Aquaculture Systems (RAS) require larger investment costs than traditional flow-through systems, RAS enables controlled production environment enabling programming production and sale, which is a prerequisite in today's markets.

As Hungary is rich in warm underground water, intensive aquaculture operations use geothermal energy to heat the production system. We developed our conception plan based on the hypothesis that geothermal water is freely available. Regarding system construction plan, in our design we propose concrete raceway tanks as main production space in grow-out and pre grow-out phase. For earlier life stages we recommend polypropylene rearing tanks. Buildings hosting the production facilities are designed to be built from light structure panels.

Feeding strategy is designed with the hypothesis that cheap, low-medium quality feed are used, because these type of African catfish feeds are produced in the region and feed transportation costs can be minimized. For larger farms we propose to farm African catfish along the entire life cycle, while smaller farms (<100 t/year) can rely on seed from external suppliers.

For assessing technical, purchasing and administrative economies of scale (see Annex II), we developed conceptual plan for two different farm sizes: with an output of 500-700 tonnes/year and 50-70 tonnes/year respectively. We designed the 500-700 t/year capacity farm to culture catfish in all life stages from hatching to market-size, while the smaller farm was designed to rely on fingerlings of 50g from external source.

Based on earlier experiences, we propose to partition the life cycle of African catfish into the following rearing phases:

- Broodstock keeping
- Breeding
- Fry rearing (up to 1g)
- Fingerling rearing (from 1 g to 10 g)
- Large fingerling rearing (from 10 g to 40-50 g)
- Yearling rearing (from 40-50 g to 200-300 g)
- Grow-out stage/ Table-fish rearing (from 200-300 g to market size)

Based on available market information we calculate with a market size of 1500-2000 g. In the smaller system, the last two rearing phases are recommended to be practiced.

Considering the frequency of selling the output, we propose a marketing schedule that is based on 2 or 4 weekly cycles. This allows to sell fish on the same day of the weeks (i.e. on Mondays) and to organize the labour in weekly cycles as the whole biomass management plan will be established accordingly. This means that propagation may take place on an exact day of the week (e.g Friday, biweekly or every 4 week), fingerlings may be harvested from fingerling tanks and transported to large fingerling tanks on an other day (e.g. Thursday), large fingerlings may be transported to yearling tanks e.g. on Wednesday, yearling may be transported to grow-out tanks 0e.g. on Tuesday. This weekly schedule of biomass transition from hatchery to marketing developed on the principles of *queuing theory* helps to minimize personnel costs by optimizing the use of labour input.

Technical Engineering plan for an African catfish RAS farm with a capacity of 500-700 t/year

As it was written above, the production cycle of African catfish is proposed to be partitioned into 7 stages in farms covering the intire life cycle. Consequently, farms must be divided into 7 sub-systems: 1. broodstock keeping unit; 2. Breeding unit; 3. Nursing unit; 4. Fingerling rearing system; 5. Large fingerling rearing system; 6. Yearling rearing system and 7. grow-out system.

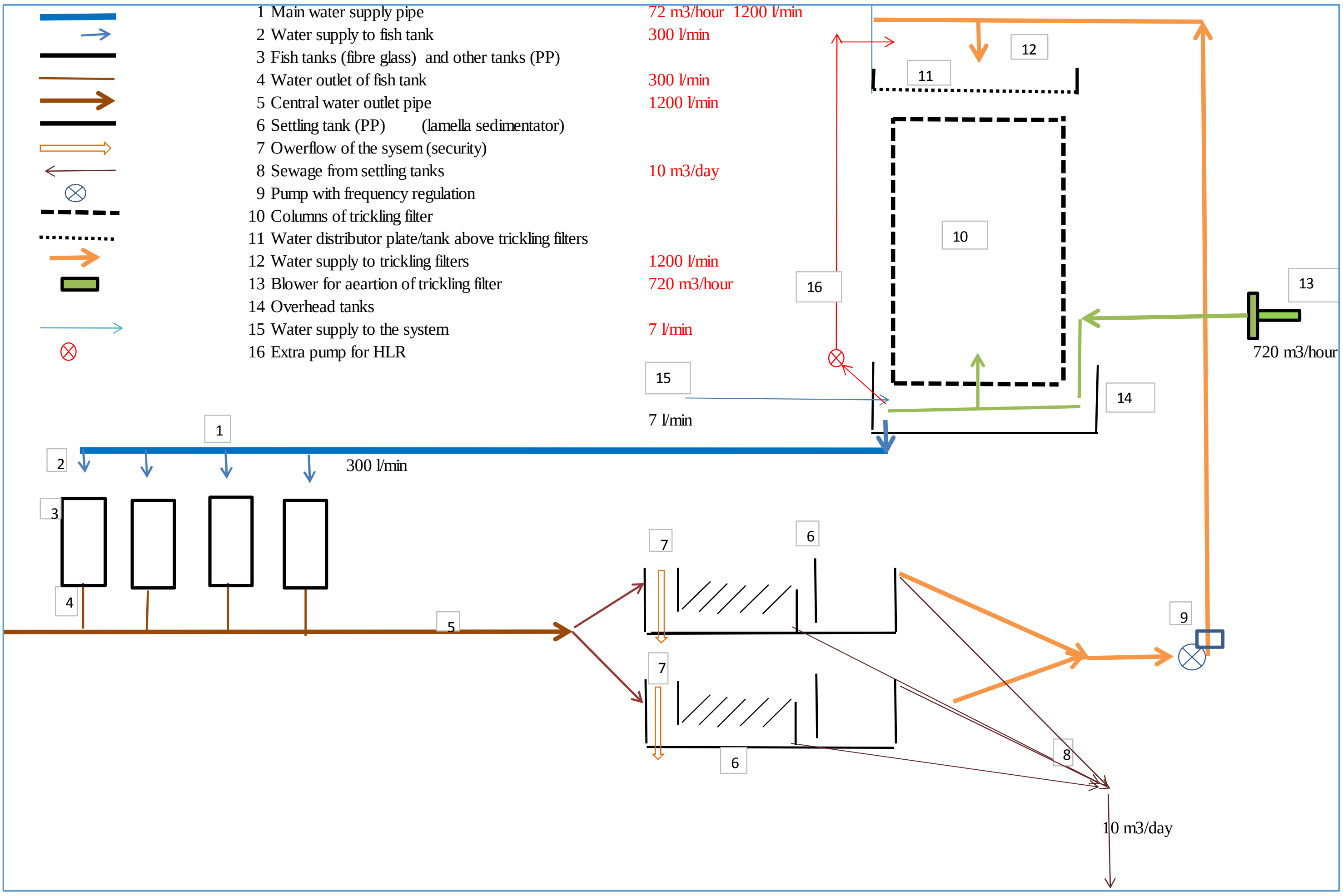
A, Broodstock keeping unit

For the broodstock keeping unit we propose to build a 36m^3 system consisting of 4 pc of 9m^3 concretre raceway tanks with lamella sedimentator and trickling filters. The size of filtering units was calculated so that 1 ton of broodstock can be kept with a feeding rate of 0.8 % of biomass day^{-1} (8 kg feed/day). The water exchange rate is designed to be 2 times/hour, meaning that pumps and pipes should be capable of transporting 72 m^3 of water/hour with a total pumping height of 5.2 m. Further specifications and cost of the system can be found in the table below, while the graph below provides a schematic view on the integration of system elements.

COMPONENTS AND INVESTMENT COSTS OF BROODSTOCK KEEPING UNIT

COMPONENT	Function, Specification, size	Quantity	Unit price	Investment cost
FISH TANKS	9 m^3 (2m x 3m x 1.5 m concrete raceways)	4 tanks	2000 €/tank	8 000 €
PUMP	72 m^3/hour capacity, pumping height=5.2m	1 pc	1 000 €	1 000 €
BLOWER FOR AERATION	Enabling 720 m^3/hour aeration of biofilter	1 pc	1 200 €	1 200 €
BIOFILTER MEDIA	It has to cope with a TAN loading of 0.35 kg/day BIOBLOCK 200 m^2/m^3, TAN removal rate=0.4g/m^2/day.	5 m^3	240 €/m^3	1 200 €
LAMELLA SEDIMENTATOR	TETRAFLOK 150 m^2/m^3	7 m^3	250 €/m^3	1 750 €
TANK FOR SEDIMENTATOR	2 polypropylene tanks, 3.6 m^3 each	7.2 m3	160 €/m^3	1 150 €
PIPEWORKS, TAPES		23 m	10 €/m	230 €
OVERHEAD TANK	PP tank	1.6 m^3	160 €/m^3	260 €
TOTAL				**14 790 €**

Schematic view of the proposed broodstock keeping unit



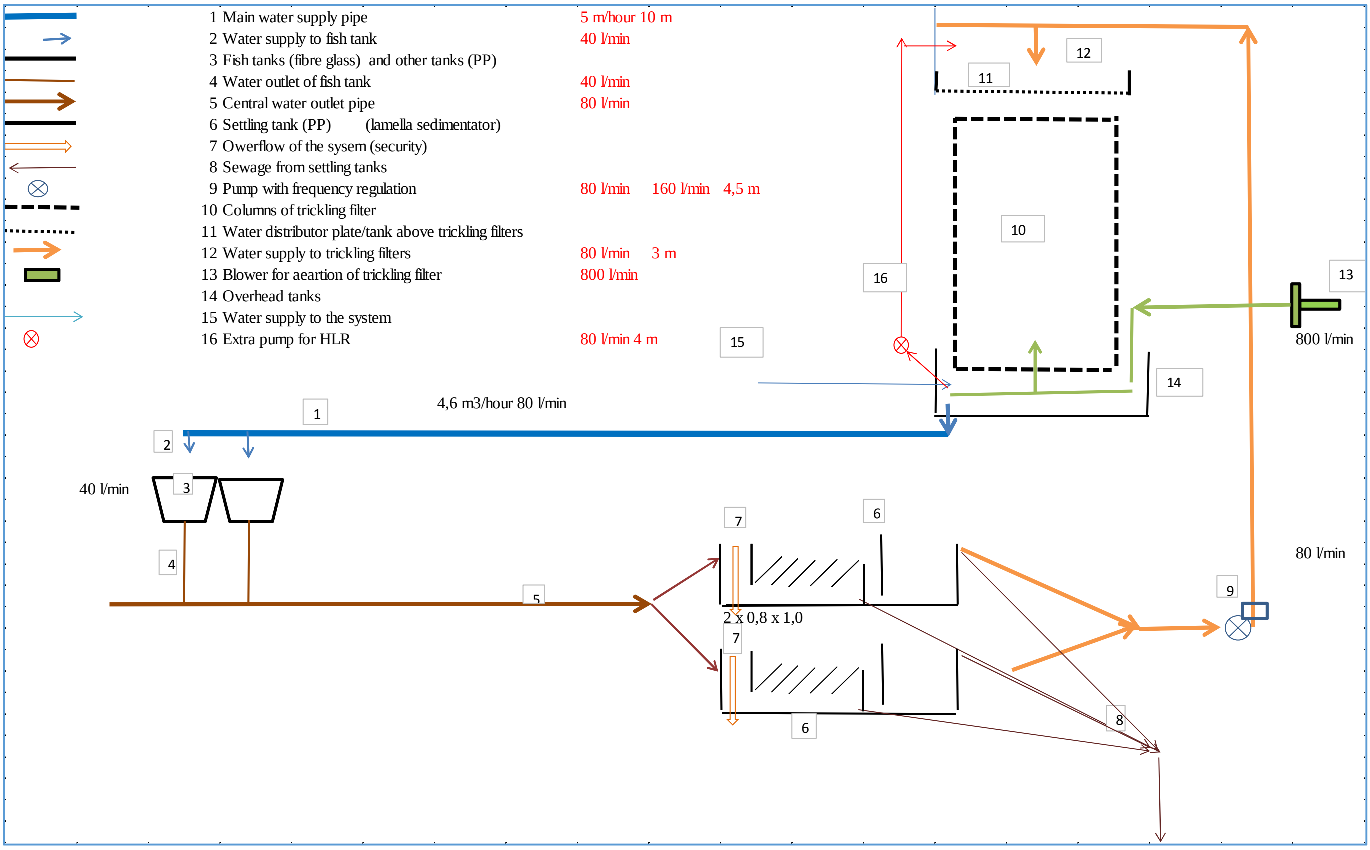
B, Nursing unit

For nursing the catfish from size of 0.01 g to 1 g we propose to build a system consisting of 6 pc of 0.8m^3 PP tanks with lamella sedimentator and trickling filters. As different fry batches need to be kept in separated water circles, the nursing system is divided into 3 independent systems, with 2 tanks each. Maximum allowable biomass density is 35-40 kg/m^3 at this life stage, maximum feed loading is 10 kg per subsystem (calculated from feeding table and biomass management plan). Filters and aeration were designed with respect to these parameters.

COMPONENTS AND INVESTMENT COSTS OF NURSING UNIT

SYSTEM COMPONENT	*Specification, size*	*Quantity*	*Unit price*	*Cost*
PUMP WITH FREQUENCY REGULATION	*3 pumps, 4.8 m^3/h capacity (height = 5.5m)*	*3 pc*		*1500 €*
BLOWER FOR AERATION OF TRICKLING	*48 m^3/hour capacity*	*3 pc*		*1200 €*
PUMP FOR HLR		*3 pc*		*600 €*
BIOFILTER MEDIA	*BIOBLOCK 200, 7.5 m^3 is required per subsystem (TAN loading rate is 0.6 kg/day/subsystem)*	*22.5 m^3*	*240 €/m^3*	*5400 €*
UPFLOW FILTER	*MBBR media, 2 m^3 per sub-system*	*6 m3*	*600 €/m3*	*3600 €*
LAMELLA SEDIMENTATOR	*TETRAFLOK, 2 m^3 per subsystem*	*6 m^3*	*250 €/m^3*	*1500 €*
SEDIMENTATION TANK	*2 Polypropylene tank per subsystem, 1.6 m^3 each*	*9.6 m3*	*160 €/m^3*	*1520 €*
FISH REARING TANKS	*0.8 m^3 Polypropylene tanks*	*6 tanks*	*820 €/tank*	*4920 €*
OVERHEAD TANKS	*PP tanks, 1,5 x 1,5 x0,5 m*	*3*	*160 €/m^3*	*520 €*
TOTAL				**20 760 €**

Schematic view of 1 sub-system in the proposed nursing system



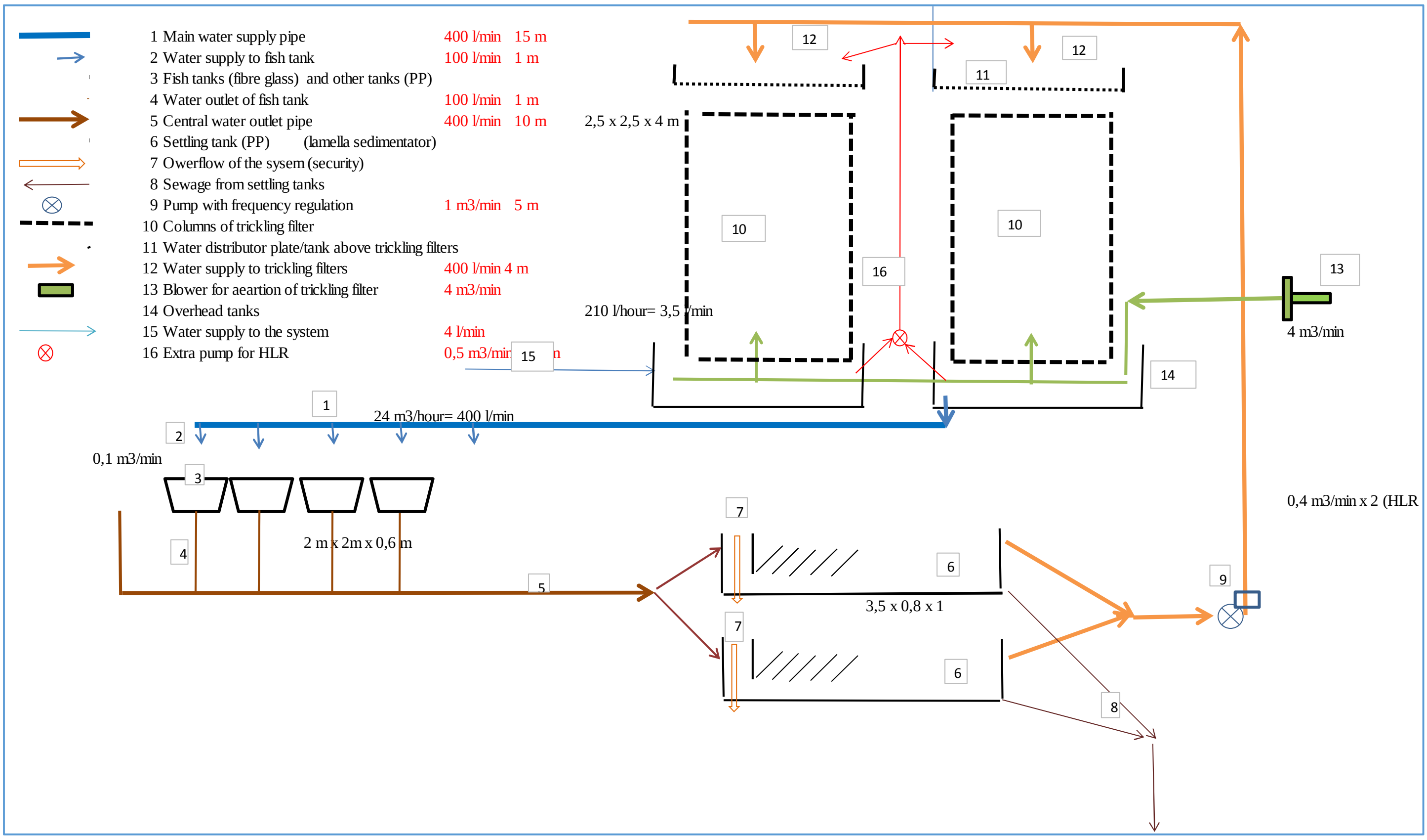
C, Fingerling rearing unit

For rearing the catfish from size of 1 g to 10 g we designed a fingerling culture unit of 8 m^3 in total that contains 4 PP tanks (2 m^3 each) with trickling filter and lamella sedimentator. As maximum allowable biomass density at this stage (150-200 kg/m^3) at this life stage then in the previous ones and the maximum feed loading is 80-90 kg/day for the entire system, filtering capacity need to be relatively larger. Thus, biolfilters account for larger share in total investment costs than in the previous systems. The water exchange rate in the system is 3 times/hour.

COMPONENTS AND INVESTMENT COSTS OF FINGERLING REARING SYSTEM

SYSTEM COMPONENT	*Specification, size*	*Quantity*	*Unit price*	*Cost*
Pump with frequency regulation	*24 m^3 / hour capacity, 6.2 m height*	*1 pc*		*1 200 €*
Blower for aeration of trickling	*240 m^3/hour aeration of biofilter*	*1 pc*		*750 €*
Pump for HLR		*1 pc*		*700 €*
Biofilter media	*BIOBLOCK 200 m^2/m^3, TAN removal rate=0.4g/m^2/day; (TANproduct=4 kg/day)*	*50 m^3*	*240 €/m^3*	*12 000 €*
Lamella sedimentator	*TETRAFLOK 150m^2/m^3*	*5 m^3*	*250 €/m^3*	*1 250 €*
Sedimentation tank PP	*2 x 2.8 m3*	*5.6 m^3*	*160 €/m^3*	*900 €*
Fish rearing tank	*2 m^3 PP tanks*	*4 tanks*	*820 €/tank*	*3 280 €*
Overhead tanks	*PP tanks, 2 x 4,5 m3*	*9 m3*	*160 €/m^3*	*1 440 €*
Pipeworks, tapes	*15 m incl. fittings*		*2,5 €/m*	*50 €*
Total				**21 570 €**

Schematic view of the proposed fingerling rearing system



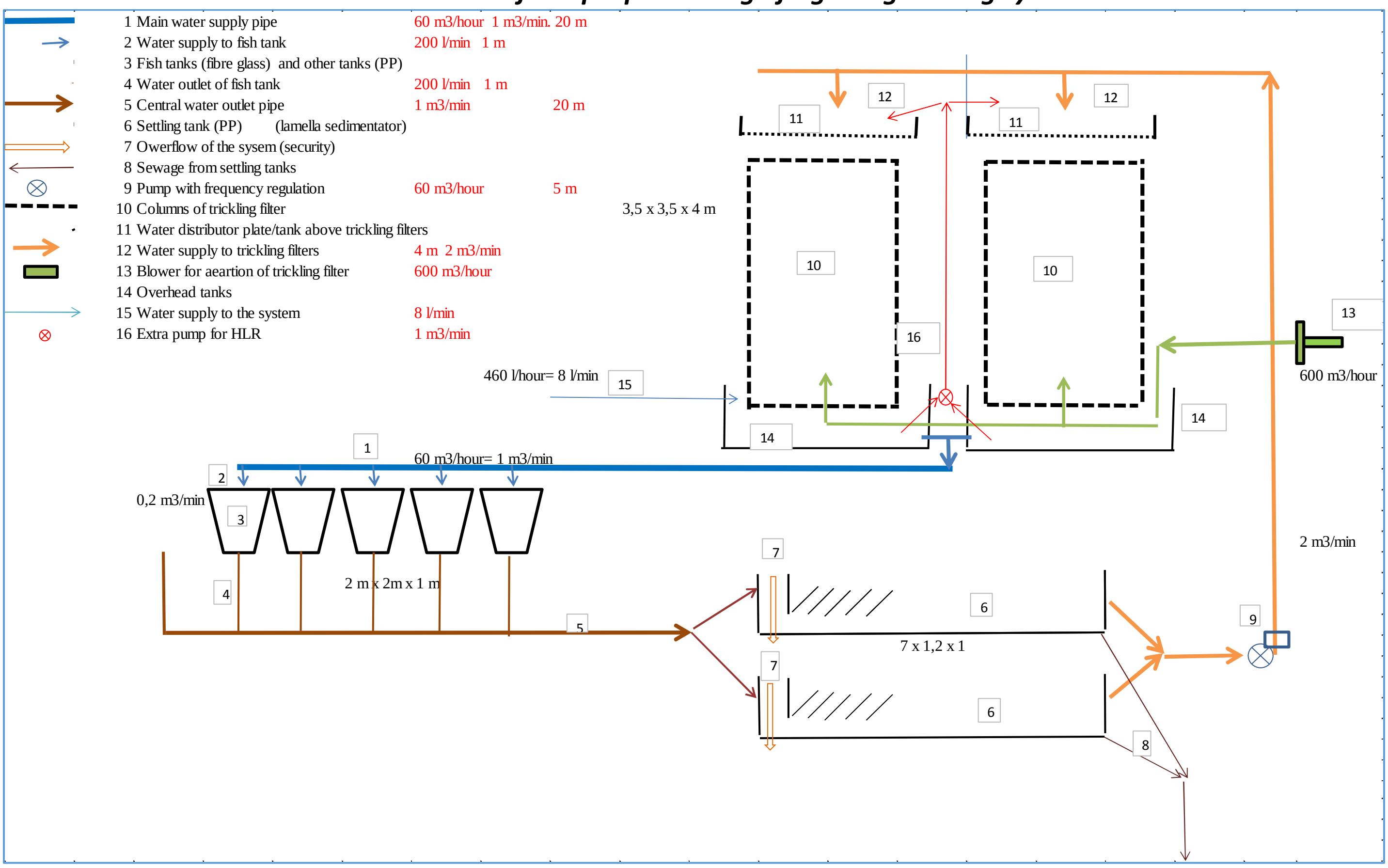
D, Large fingerling rearing unit

For culturing 10 g size fish to 40-60 g we designed a unit of 20 m^3 in total that contains 5 PP tanks (4 m^3 each) with trickling filter and lamella sedimentator. Maximum allowable biomass density at this stage is around 300 kg/m^3. The filters were sized so that the maximum allowable TAN production is 8.3 kg/day (max feed load is around 190 kg/day). The water exchange rate in the system is 3 times/hour. Further specifications and cost of the system can be found in the table below, while the graph below provides a schematic view on the integration of system elements.

COMPONENTS AND INVESTMENT COSTS OF LARGE FINGERLING REARING SYSTEM

SYSTEM COMPONENT	*Specification, size*	*Quantity*	*Unit price*	*Cost*
PUMP WITH FREQUENCY REGULATION	*60 m^3 / hour capacity, 6.2 m height*	*1 pc*		*1 200 €*
BLOWER FOR AERATION OF TRICKLING	*600 m^3/hour aeration of biofilter*	*1 pc*		*950 €*
PUMP FOR HLR		*1 pc*		*700 €*
BIOFILTER MEDIA	*BIOBLOCK 200 m^2/m^3*	*100 m^3*	*240 €/m^3*	*24 000 €*
LAMELLA SEDIMENTATOR	*TETRAFLOK 150m^2/m^3*	*11 m^3*	*250 €/m^3*	*2 750 €*
SEDIMENTATION TANK	2 x 8.4 m^3 PP tanks	*16.8 m^3*	*160 €/m^3*	*2 700 €*
FISH REARING TANK	*4 m^3 PP tanks*	*5 tanks*	*1100 €/tank*	*5 500 €*
OVERHEAD TANKS	*PP tanks, 2 x 4.3 m3*	*8.6 m3*	*160 €/m^3*	*1 400 €*
PIPEWORKS, TAPES	*15 m + fittings*		*10 €/m*	*150 €*
TOTAL				**39 350 €**

Schematic view of the proposed large fingerling rearing system



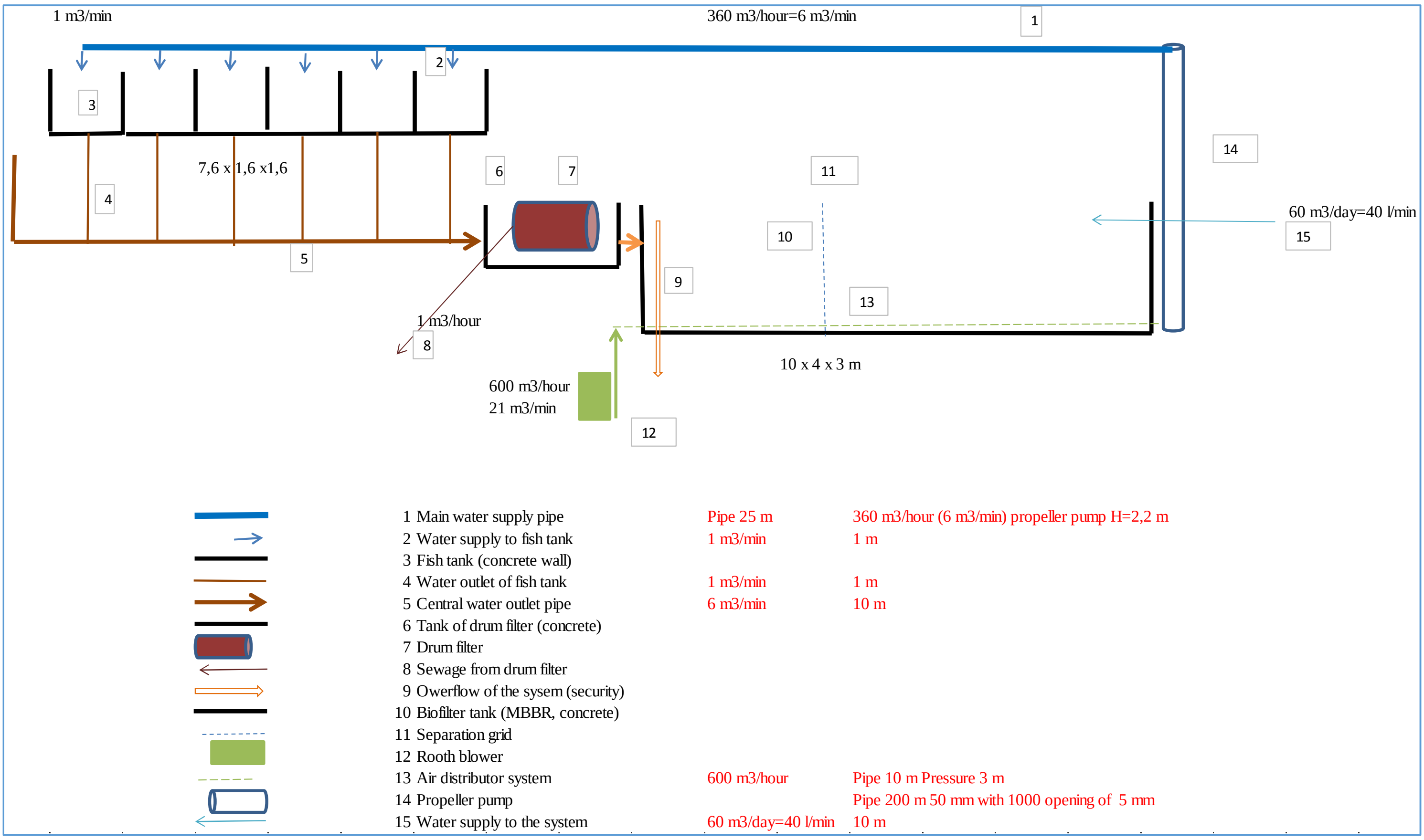
E, Yearling rearing unit

For culturing the catfish from 40-60 g to 200-300 g (yearling stage) we designed a unit of 120 m^3 in total that contains 6 concrete raceway tanks (20 m^3 each) with moving bed bioreactors and drum filters. Maximum allowable biomass density at this stage is around 300-350 kg/m^3, the maximum feed loading is 190 kg/day. The filters were sized so that the maximum allowable TAN production is 8.3 kg/day. The water exchange rate in the system is 3 times/hour. Further specifications and cost of the system can be found in the table below, while the graph below provides a schematic view on the integration of system elements.

COMPONENTS AND INVESTMENT COSTS OF YEARLING REARING SYSTEM

SYSTEM COMPONENT	*Specification, size*	*Quantity*	*Unit price*	*Cost*
Propeller pump with frequency regulation	*360 m^3 / hour capacity, 2.2m pumping height*	*1 pc*		*18 000 €*
Drum filter	*HY 1603, 100 l/sec removal of SS*	*1 pc*		*14 000 €*
Root blower with frequency regulation	*At least 600 m^3/hour capacity*	*1 pc*		*11 000 €*
Water supply pump		*1 pc*		*200 €*
Biofilter media	*Inter Aqua Cruler Advanced I.*	*61 m^3*	*600 €/m^3*	*36 600 €*
Tank for biofilter media	*120 m^3 concrete tank*	*1 tank*		*12 000 €*
Fish rearing tanks	*20 m^3 concrete tanks (7.6m x 1.6m x 1.6m)*	*6 tanks*	*3700 €/ tank*	*22 200 €*
Pipeworks, tapes	*50 m + fittings*		*20 €/m*	*1 000 €*
TOTAL				**101 000 €**

Schematic view of the proposed yearling rearing system



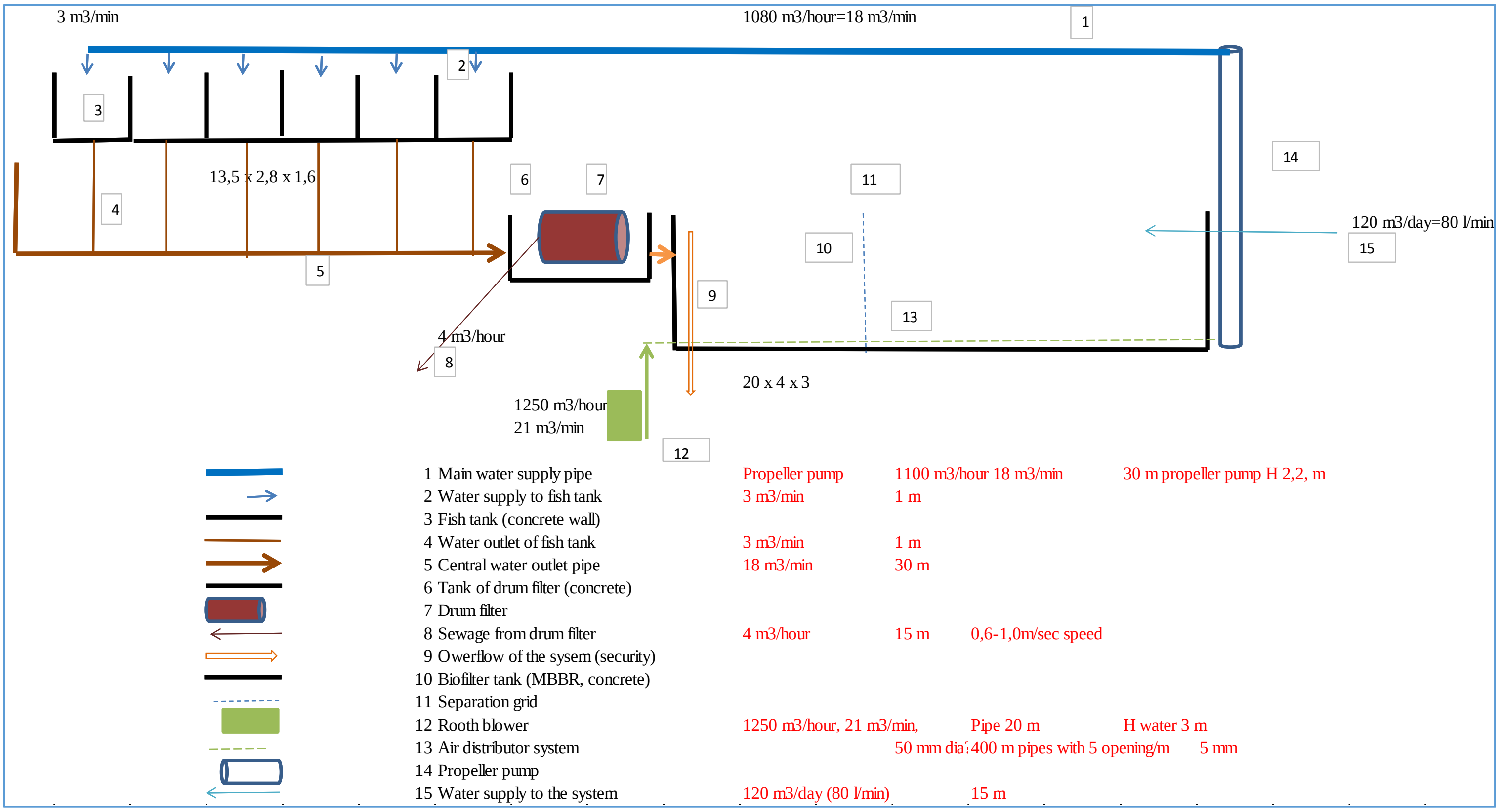
F, Grow out unit

For culturing the catfish from 200-300 g to market size (which is around 1.5-2 kg in Central Europe) we propose to build 12 concrete raceway tanks of 60 m^3 (in total 720 m^3). The filtering unit should consist of moving bed bioreactors and drum filters. Maximum allowable biomass density at this stage is high, 400-500 kg/m^3, the maximum feed loading is 2200 kg/day. The filters were sized so that the maximum allowable TAN production is 85 kg/day. The water exchange rate in the system is 3 times/hour. Further specifications and cost of the system can be found below. The graph below provides a schematic view on the integration of system elements.

COMPONENTS AND INVESTMENT COSTS OF GROW-OUT SYSTEM

Name of the system component	*Specification, size*	*Quantity*	*Unit price*	*Cost*
Propeller pump with frequency regulation	*2160 m^3 / hour capacity, 2m p. height*	*1 pc*		*22 000 €*
Drum filter	*HY 1606, 300 l/sec removal of SS*	*2 pc*	*23 000 €/pc*	*46 000 €*
Root blower with frequency regulation	*at least 1250 m^3/hour capacity*	*2 pc*	*13 000 €/pc*	*26 000 €*
Water supply pump		*2 pc*	*300 €/pc*	*600 €*
Biofilter media	*Inter Aqua Cruler Advanced I.*	*236 m^3*	*600 €/m^3*	*141 600 €*
Tank for biofilter media	*250m^3 concrete tanks*	*2 tanks*	*12000 €/tank*	*24 000 €*
Fish rearing tank	*60 m^3 concrete tanks (13.5m x 2.8m x 1.6m)*	*12 tanks*	*7840 €/tank*	*94 080 €*
Pipeworks, tapes	*2x 25 m Diameter 40 cm*		*160 €/m*	*8 000 €*
Total				**308 280 €**

Schematic view of the proposed grow-out system (1 of the 2 sub-systems)



F, BREEDING UNIT

The smallest system to be built will serve for keeping the fish and eggs during the breeding days. We propose to acquire two tanks of 2 m^3 each (suggestion SDK 18-25) and 10 pieces of Zoug jars (SDK). Further information is not attached as it is a relatively simple system, it requires a moderate water flow.

G. SUMMARY ON TOTAL INVESTMENT COSTS NEEDED TO CONSTRUCT THE SYSTEM

The table below provides an overview of the investment costs that are required to establish the production systems described in the previous section. The total amount is 0.91 million EUR. It has to be noted that this amount covers only the acquirement of necessary fixed capital, and does not include the operating capital required to start up the business.

For the purpose of assessing average fixed cost, which will be needed when calculating economies of scale, we computed the annualized amount of fixed costs, which means that instead of calculating with the investment cost of €0.9 million occurring at one time, this amount divided into equal parts and spread over the useful life of the investment (estimated to be 20 years)[2].

System equipment, machinery		**508 750 €**
	Broodfish keeping system	*14790 €*
	Breeding unit	*3000 €*
	Nursing system	*20760 €*
	Fingerling rearing system	*21570 €*
	Large fingerling rearing system	*39350 €*
	Yearling rearing system	*101000 €*
	Grow-out system	*308280 €*
Building (1500 m^2)		**300 000 €**
Land, public utilities (electricity, gas, water, waste water system), well drilling		**100 000 €**
Total investment		**908 750 €**
Annual capital costs (10% interest, 5% depreciation → CRF 11.74 %)		**106 740 €**

[2] Annual amount of the financial costs is calculated with Capital Recorvery Factor formula ($\boldsymbol{CRF}$ = Investment costs x $\frac{i(1+i)^n}{(1+i)^n-1}$), which takes into account the useful life (n is number of years) and the interest rate (i).

Bio-plan of the system (growth, mortalities, feeding, biomass management) for the farm with 500-700 t/year output

Growth rate, feeding rate and mortality of African catfish over time was determined to each of the following stages as follows:

Grow-out period (from 200-300g to 1,5-2 kg):

- Growth rate was determined with a parabolic growth function formula, that contains time implicitly: $dw/dt = 0.11*w^{0.63}$ Based on this equation it takes 24 weeks for the individuals to reach 1.6 kg from 0.3 kg starting weight (0.5 kg is reached within 6 weeks, while 1 kg is reached in 16 weeks)
- Daily feeding rate was determined based on the following equation $Feed/day = 0.18*w^{0.6}$
- Mortality is assumed to be 14% over the grow-out rearing period of 24-week

Yearling rearing period (from 50 g to 200-300g):

- Growth rate was determined with a parabolic growth function formula: $dw/dt = 0.2*w^{0.56}$ Based on this equation it takes 12 weeks for the individuals to reach 300g from 50g starting weight
- Daily feeding rate was determined based on the following equation $Feed/day = 0.18*w^{0.6}$
- Mortality is assumed to be 18% over a 12-week period of yearling rearing

Large fingerling rearing period (from 10 g to 50g):

- Growth rate was determined with a parabolic growth function formula: $dw/dt = 0.38*w^{0.49}$ Based on this equation it takes 22-23 days for the individuals to reach 50g from 10g starting weight
- Daily feeding rate was determined based on the following equation $Feed/day = 0.17*w^{0.6}$
- Mortality is assumed to be 32% over the large fingerling rearing period (23-24 days)

Fingerling rearing period (from 1 g to 10g):

- Growth was calculated based on an exponential growth formula ($weight = 1*e^{0.087*t}$): it takes 25 days to reach 10 g from 1 g size
- Daily feeding rate was determined based on the following equation $Feed/day = 0.17*w^{0.6}$
- Mortality is assumed to be 36% over the fingerling rearing period (25 days)

Nursing period (from 1 g to 10g):

- Growth was calculated based on an exponential growth formula ($weight = 0.025*e^{0.116*t}$): it takes 5 weeks (34-35 days) to grow newly hatched catfish fries (0.025 g) to 1 g
- Mortality is assumed to be 45% over this period
- Daily feeding rate was determined based on a usual parabolic equation, but since individual weight cannot be measured at this time, it is useful to follow the following procedure: the daily feeding rate as % of bodyweight starts from 52% and decreased equally along the nursing period to 17%.

Broodfish keeping:

- Daily feeding rate is 0.8% of the bodyweight

Biomass management plan in the system

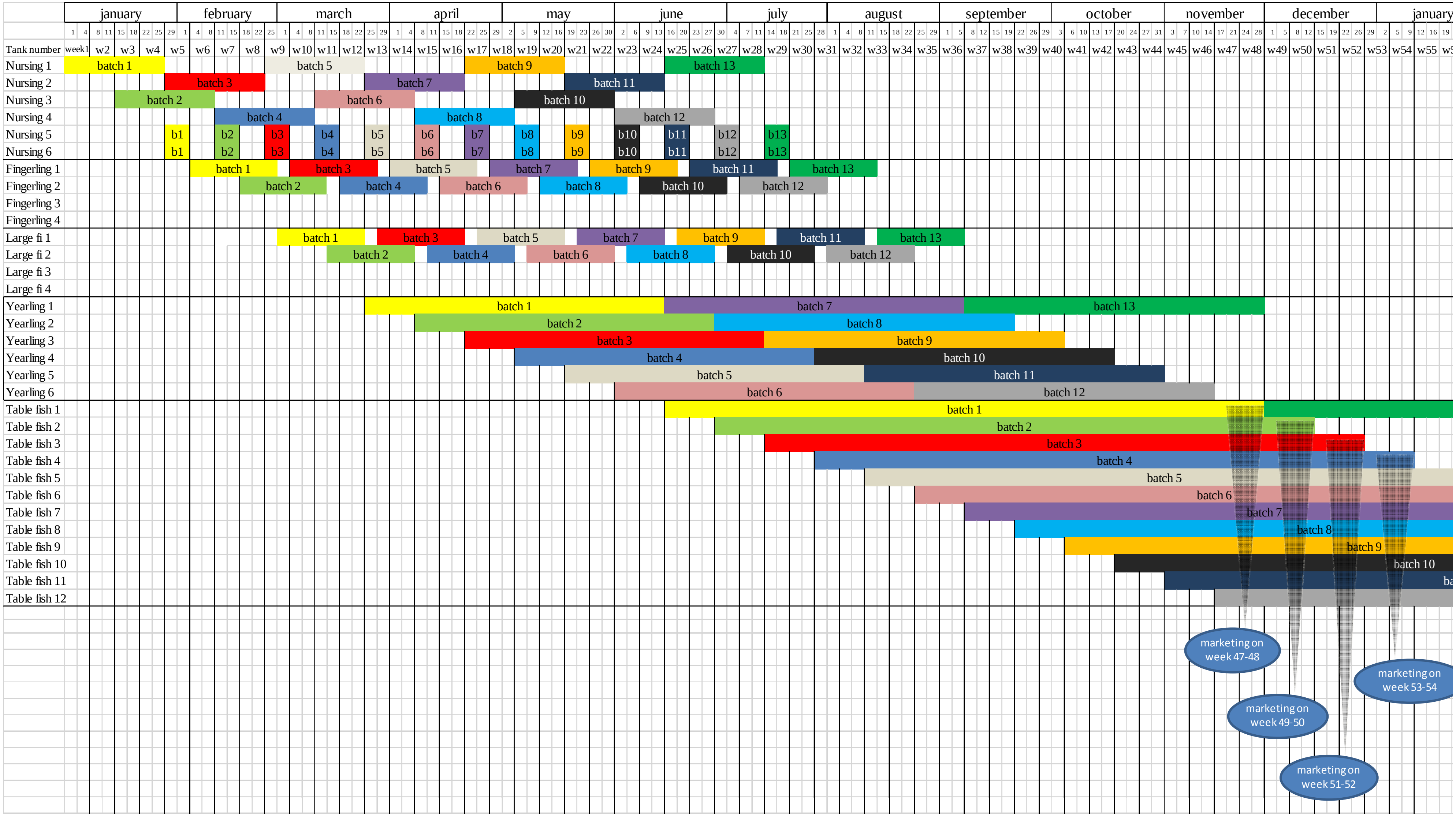
Biomass management plan is the designed plan to move stocks in between tanks so that production space (tanks/cages/ponds) is maximally utilized over time, taking into account i) biological-technological factors (biomass density, filtering capacity); ii) managerial factors (labour schedule; propagation frequency) and iii) market factors (timing of marketing fish).

We designed the biomass management plan to the farm taking into consideration the following factors:

- 5 life stages (broodfish and hatching are excluded): nursing, fingerling rearing, large-fingerling rearing, yearling rearing, grow-out rearing
- Length of cycles in different life stages should be an integral multiple of 7 days, so that labour schedule can be designed based on weekly cycles. E.g. if it takes 23 days for the individuals to complete the large fingerling phase (to reach 50 g from 10 g) then the systems is left empty for 5 additional days, so that stocking and transportation can occur always at the same day of the week.
- Bi-weekly marketing of fish. As we designed our system to produce 500-700 tons annually, it means that 20-27 tons of fish need to be marketed every 2nd week. If we target the higher number and calculate with individuals of 1.6 kg, then batch size of 17,000 is required at the end of the production cycle
- Bi-weekly propagation. Calculating with the required batch size and mortalities, it is needed to hatch 100,000 fries every second week.

The figure in the next page presents the biomass transition plan of the batches across the life stages. Each different colour denotes a different batch. Each row in the figure represent a different tank, while columns represent weeks of the year (one column is equal to half of a week). Thus, horizontal coloured lines illustrates how different tanks occupied by different batches over time. It takes 48 weeks for each batch to reach market size: 5 weeks are spent in nursing tanks , (0.8 m^3), 3.5 weeks in fingerling tanks (2 m^3), 3.5 weeks in large fingerling tanks (4 m^3), 12 weeks in yearling tanks (20 m^3), and 24 weeks in grow-out tanks (60 m^3).

Utilisation rate of smaller tanks are lower, because growth performance is more heterogenous in earlier life stages, and slow-grower batches will need more space. Thus more empty periods and tanks are designed.


january
february
march
april
may
june
july
august
september
october
november
december
january
Tank number
week1 w2 w3 w4 w5 w6 w7 w8 w9 w10 w11 w12 w13 w14 w15 w16 w17 w18 w19 w20 w21 w22 w23 w24 w25 w26 w27 w28 w29 w30 w31 w32 w33 w34 w35 w36 w37 w38 w39 w40 w41 w42 w43 w44 w45 w46 w47 w48 w49 w50 w51 w52 w53 w54 w55
Nursing 1
batch 1
batch 5
batch 9
batch 13
Nursing 2
batch 3
batch 7
batch 11
Nursing 3
batch 2
batch 6
batch 10
Nursing 4
batch 4
batch 8
batch 12
Nursing 5
b1 b2 b3 b4 b5 b6 b7 b8 b9 b10 b11 b12 b13
Nursing 6
b1 b2 b3 b4 b5 b6 b7 b8 b9 b10 b11 b12 b13
Fingerling 1
batch 1
batch 3
batch 5
batch 7
batch 9
batch 11
batch 13
Fingerling 2
batch 2
batch 4
batch 6
batch 8
batch 10
batch 12
Fingerling 3
Fingerling 4
Large fi 1
batch 1
batch 3
batch 5
batch 7
batch 9
batch 11
batch 13
Large fi 2
batch 2
batch 4
batch 6
batch 8
batch 10
batch 12
Large fi 3
Large fi 4
Yearling 1
batch 1
batch 7
batch 13
Yearling 2
batch 2
batch 8
Yearling 3
batch 3
batch 9
Yearling 4
batch 4
batch 10
Yearling 5
batch 5
batch 11
Yearling 6
batch 6
batch 12
Table fish 1
batch 1
Table fish 2
batch 2
Table fish 3
batch 3
Table fish 4
batch 4
Table fish 5
batch 5
Table fish 6
batch 6
Table fish 7
batch 7
Table fish 8
batch 8
Table fish 9
batch 9
Table fish 10
batch 10
Table fish 11
Table fish 12
marketing on week 47-48
marketing on week 49-50
marketing on week 51-52
marketing on week 53-54

Economic calculations for the farm with 500-700 tonnes/year output

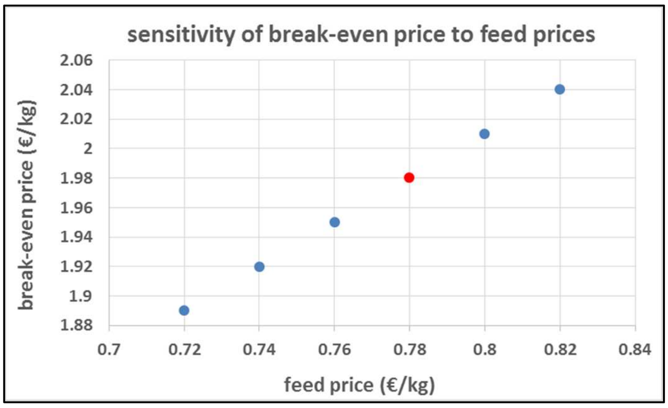
Profitability of the investment is estimated on the ground of enterprise budget, which predicts incomes and expenses in a typical year. The following assumptions were made when calculating the enterprise budget:

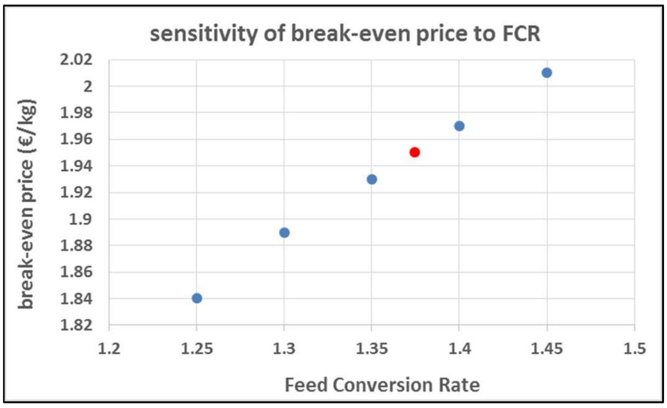
- Annual production is 708 tonnes of African catfish (based on calculation from above described bio-plan)
- Producer price of African catfish is 2 €/kg. This is the prevalent producer price in Hungary in the mass market. Smaller quantities can be sold at higher price by direct selling to end consumers or restaurants.
- Annual capital costs are €106,687 (see calculation above)
- Feed consumption is 973 tonnes per year (based on feeding rate equations), FCR is 1.38
- Feed price is 0.76 €/kg. (Standard price of the feed is 0.8 €/kg, but as ~1 million tonnes of feed is purchased based on long term contract, a 5 % discount is calculated in feed prices.) Quality of feed corresponds to the above described Feed Conversion Rate. Alternative feed can also be used but the higher the quality of the feed the higher the price is and the better the Feed Conversion Rate is.
- 8 persons are required to operate the system, including 1 manager, 1 clerk and 6 physical workers
- The cost of a person year is €12,500
- Electric energy requirement of the system is 450,000 kWh per year
- Cost of electricity is 0.13 €/kWh
- There are no seed costs (The facility is designed to carry out full life-cycle rearing, including broodstock maintenance)
- There are no oxygen costs (Although oxygen is a major cost item in intensive aquaculture, being an air breathing species African catfish does not require diluted oxygen)
- Post-harvest (transportation, packaging, value addition, marketing) for a farm with an output of 500-700 t/year is estimated to be 0.3 €/kg production. The post-harvest cost per unit is a function of production level, as lower production can be marketed at local markets with lower transportation and processing costs, while higher production require a value-addition phase (processing) to be placed on the market
- Other cost items are estimated to be 10 % of the sum of major cost items (capital costs, feed, seed, electricity, labour, oxygen). Other costs include both direct production costs (medical treatments of fish, gas and diesel, repairs and maintenance) and indirect administration costs (insurance, office supplies, telephone, legal/accounting).
- Cost of operating capital is determined on the ground of the following assumptions: operating capital is assumed to be used for 5 months on average; the interest rate is 8%. As 1.2 million € is needed for running costs on annual basis, average standing stock of operating credit is 500,000€.

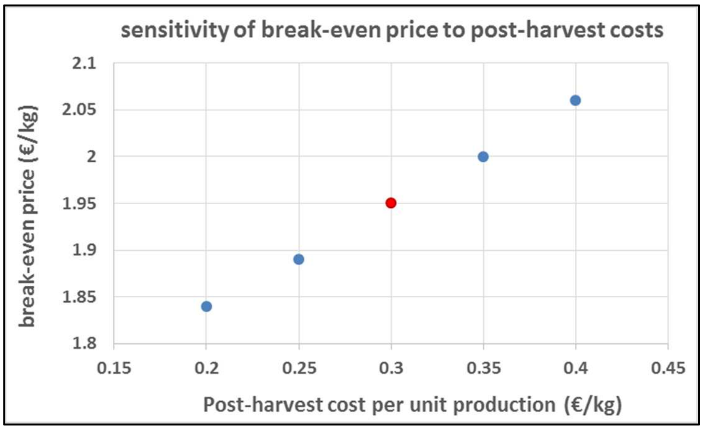
Estimated Annual Costs and Returns for the 700 t/year African Catfish RAS farm

ITEM	QUANTITY	UNIT PRICE/COST	TOTAL
REVENUE	**708,000 kg production**	**2 €/kg**	**€ 1 416,000**
CAPITAL COSTS ON INVESTMENT	908,750 € investment	11.74 %	€ 106,687
FEED COSTS	973,000 kg feed	0.76 €/kg	€ 739,480
LABOUR COST	8 FTE/year	12500 €/FTE/year	€ 100,000
ENERGY COST	450,000 kWh electricity	0.13 €/kWh	€ 58,500
POST-HARVEST COST	708,000 kg production	0.3 €/kg	€ 212,400
OTHER COSTS	1,217,067 € total direct costs	10%	€ 121,707
INTEREST ON OPERATING CAPITAL	500,000 € operating capital	8%	€ 40,000
TOTAL COST			**€ 1,378,774**
NET RETURNS TO OPERATOR RISK			**€ 37,226**
BREAKEVEN PRICE (AVERAGE PRODUCTION COST)			**1.95 €/kg**

The results show that the farms is hardly profitable with the given assumptions (0.05 € profit on 1 kg fish and 37,226€ profit on whole farm). Sensitivity analysis graph below how unit production cost (break-even price) varies along with changed assumptions regarding major bio-economic influencing factors of profitability. Other factors like electricity consumption, cost of electricity, cost of labour, investment cost affect profitability to a limited extent, according to our calculations.







Technical plan for an African catfish RAS farm with a capacity of 50-80t/year

Contrary to large production systems (from 100 t/year), smaller production systems don't have to cover the entire life cycle of catfish farming, but rely on seeds as external input. We designed a smaller scale system which farms African catfish from 50 g size to market size. In Hungary, 50 g fingerlings can easily be bought. We propose to partition the rearing cycle into two phases: a yearling rearing phase (from 50 g to the size of 200g-300g) and a grow-out phase. Given this, 2 systems need to be constructed, one for smaller individuals and one for the larger ones.

A, Yearling rearing unit

For culturing the catfish from 50 g to 200-300 g (yearling stage) we designed a unit with 8 m^3 production space in total containing 4 fibreglass tanks (2 m^3 each). The filtering unit is proposed to be built with moving bed bioreactors and drum filters. The filters were sized so that the maximum allowable TAN production is 1.5 kg/day (corresponding to a daily feed load of 25-40 kg). The water exchange rate in the system is 3.5 times/hour.

COMPONENTS AND INVESTMENT COSTS OF YEARLING REARING SYSTEM

Name of the system component	*Specification, size*	*Quantity*	*Unit price*	*Cost*
Centrifugal pump	*25 m^3 / hour capacity, 2m p. height*	*1 pc*	*300 €/pc*	*300 €*
Drum filter	*HY 501, 8 l/sec removal of SS*	*1 pc*	*4 000 €/pc*	*4 000 €*
Reganerative blower	*at least 50 m^3/hour capacity*	*1 pc*	*400 €/pc*	*400 €*
Water supply pump		*1 pc*	*100 €/pc*	*100 €*
Biofilter media	*Inter Aqua Cruler Advanced I.*	*4.5 m^3*	*600 €/m^3*	*2 700 €*
Tank for biofilter media	*9 m^3 concrete tank*	*1 tank*	*2000 €/tank*	*2 000 €*
Fish rearing tanks	*2 m^3fibreglass tanks*	*4 tanks*	*600 €/tank*	*3 200 €*
Pipeworks, tapes		*40m*	*20 €/m*	*800 €*
Total				**13 500 €**

B, Grow out unit

For culturing the catfish in the grow-out phase we propose to build 112 m^3 system consisting of 14 concrete raceway tanks of 8 m^3. Filtering process is based on moving bed bioreactors and drum filters. The filters were sized so that the maximum allowable TAN production is 10 kg/day, the maximum feed loading is 260-265 kg/day. The water exchange rate in the system is 3 times/hour. Further specification of the proposed system are listed in the table below.

COMPONENTS AND INVESTMENT COSTS OF GROW-OUT SYSTEM

System component	*Specification, size*	*Quantity*	*Unit price*	*Cost*
Centrifugal pump with frequency regulator	*300 m^3 / hour capacity, 2m p. height*	*1 pc*	*1200 €/pc*	*1 200 €*
Drum filter	*HY 1203, 80 l/sec removal of SS*	*1 pc*	*13 000 €/pc*	*13 000 €*
Regenerative blower	*300 m^3/hour capacity*	*1 pc*	*2300 €/pc*	*2 300 €*
Water supply pump		*1 pc*	*300 €/pc*	*300 €*
Biofilter media	*Inter Aqua Cruler Advanced I.*	*35 m^3*	*600 €/m^3*	*21 000 €*
Tank for biofilter media	*70m^3 concrete tank*	*1 tank*	*8200 €/tank*	*8 200 €*
Fish rearing tanks	*8 m^3 concrete tanks (3.2 x 1.6 x 1.6 m)*	*14 tanks*	*1900 €/tank*	*26 600 €*
Pipeworks, tapes		*40m*	*20 €/m*	*800 €*
Total				**60 400 €**

C, Summary on total investment costs needed to construct the system

The table below provides an overview of the investment costs that are required to establish the production systems described above. The total amount is 163 900 EUR. It has to be noted that this amount covers only the acquirement of necessary fixed capital, and does not include the operating capital required to start up the business.

System equipment, machinery	**73 900 €**	
Yearling rearing system		*13500 €*
Grow-out system		*60400 €*
Building (300 m^2)	**60 000 €**	
Land, public utilities (electricity, gas, water, waste water system), well drilling	**30 000 €**	
Total investment	**163 900 €**	
Annual capital costs (10% interest, 5% depreciation → CRF 11.74 %)	19 252 €	

Bio-plan of the system for the farm with 50-80 t/year output

Growth rate, feeding rate and mortality of African catfish over time was determined to each of the following stages as follows:

Grow-out period (from 200-300g to 1,5-2 kg):

- Growth rate was determined with a parabolic growth function formula, that contains time implicitly: $dw/dt= 0.11*w^{0.63}$
- Daily feeding rate was determined based on the following equation $Feed/day=0.18*w^{0.6}$

Yearling rearing period (from 50 g to 200-300g):

- Growth rate was determined with a parabolic growth function formula: $dw/dt= 0.2*w^{0.56}$
- Daily feeding rate was determined based on the following equation $Feed/day=0.18*w^{0.6}$

Calculating with 1.6 kg market size, it takes 36 weeks for the individuals to reach market size from 50 g fingerling size. Mortality is assumed to be 30% over this 36-week period.

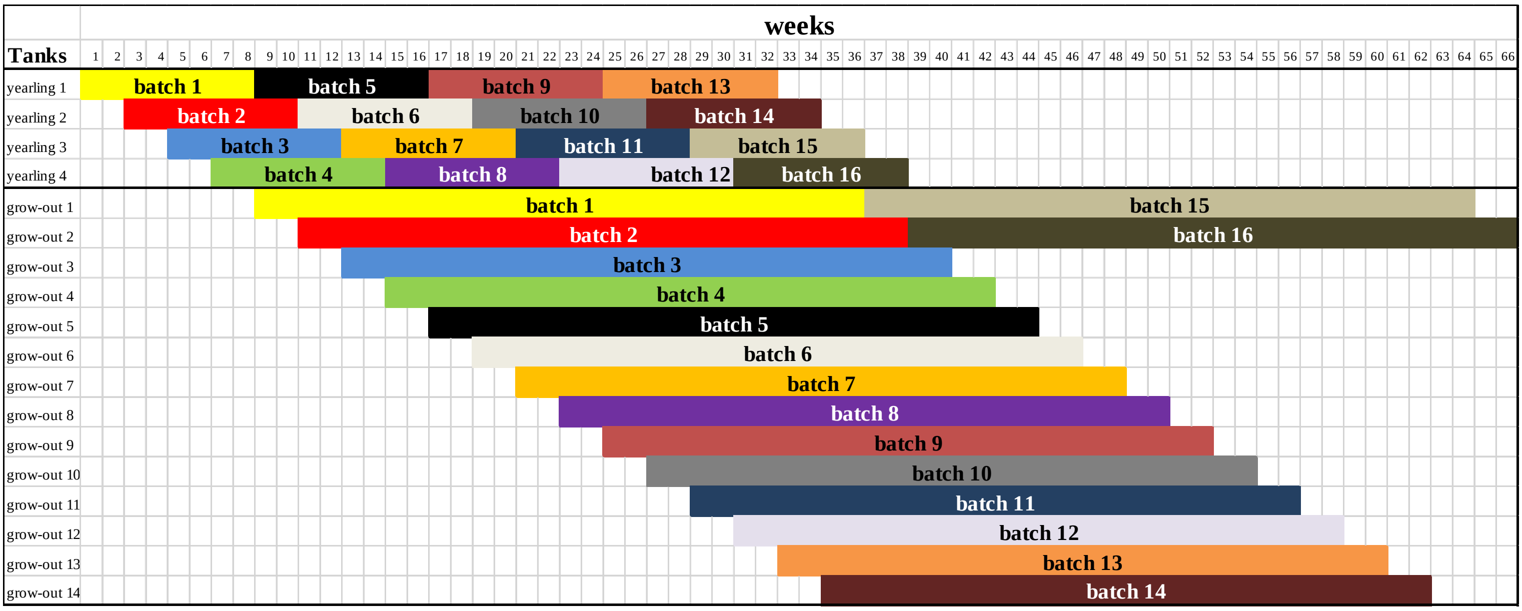
Biomass management plan in the system

We designed the biomass management plan as follows:

- 2 life stages: yearling rearing, grow-out rearing. Length of cycles in the two life stages should be an integral multiple of 7 days.
- Given the 36 week-long growing period and the tank layout structure of the system (4 yearling tanks and 14 grow-out tanks), we propose a 8 week long yearling rearing phase and a 28 week long grow out phase, with new batch arrivals in every second week (following the rules of queueing theory)
- Bi-weekly arrival of fingerling batches from external supplier implies that marketing should take place in bi-weekly cycles as well

- Taking into consideration the size of grow-out tanks (8 m^3) and maximum allowable biomass density (380 kg/m^3), 1900 individuals per batch are required to reach the markets-size age. 30% mortality implies that 2700 fingerlings should be bought in every second week (70200 per year)
- The total production per year is estimated to be 79100 kg based on the assumptions and calculations described above

The figure in the next page presents the biomass transition plan of the batches across the life stages. Each different colour denotes a different batch. Each row in the figure represent a different tank, while columns represent weeks of the year. Thus, horizontal coloured lines illustrates how different tanks occupied by different batches over time.



Economic calculations for the farm with 50-80 tonnes/year output

Smaller systems can apply mark-up pricing strategy[3] as they should be able to market their production out of the range of mass markets (which are characterized by pre-determined price and homogenous products). For this reason we did not calculate with prices and revenues, and did not define profitability indicators. Only production costs were calculated for the smaller system described above with the use of an enterprise budget, which predicts expenses in a typical year. The following assumptions were made when calculating the enterprise budget:

- Annual production is 79 tonnes of African catfish
- Contrary to the economic analysis performed for the larger system, we did not calculate with post-harvest cost for this smaller system, because producers should be able to

[3] Mark-up pricing is the practice of formulating the selling price on the basis of production cost by adding a constant percentage to the cost price of an item to arrive at its selling price.

market 70-80 tonnes per year in live/fresh form. E.g. selling directly from fish farm and/or transporting the fish to local retail or HORECA[4] markets.

- Annual capital costs are €19,252 (calculated from the investment cost table)
- Feed consumption is assumed to be 106 tonnes per year (based on feeding rate equations), FCR is 1.4 Feed price is 0.8 €/kg.
- 3 physical workers are required to operate the system. As such a small sized system would not be viable as a stand-alone economic activity, we did not calculate with office workers. Managerial and administrative tasks have to be undertaken by the main company to which the fish farm belongs. The cost of a person year is €12,500.
- Electric energy requirement of the system is 67,500 kWh per year. The cost of electricity is 0.13 €/kWh
- Cost of a fingerling of 50 g size is €0.22. 70200 fingerlings should be bought annually to run biomass plan described above.
- Other cost items are estimated to be 10 % of the sum of major cost items (capital costs, feed, seed, electricity, labour). Other costs include both direct production costs (medical treatments of fish, gas and diesel, repairs and maintenance) and indirect administration costs (insurance, office supplies, telephone, legal/accounting).
- Cost of operating capital is determined on the ground of the following assumptions: operating capital is assumed to be used for 4 months; the interest rate is 8%. (Production cycle is shorter in the smaller farm compared to the larger farm, and operating capital is used for a shorter period.)

Estimated Annual Costs for a 79 t/year African Catfish RAS farm

ITEM	QUANTITY	UNIT PRICE/COST	TOTAL
CAPITAL COSTS ON INVESTMENT	164,900 € investment	11.74 %	€ 19,242
FEED COSTS	106,000 kg feed	0.8 €/kg	€ 84,800
SEED COSTS	70,200 fingerlings	0.22 €/fingerling	€ 15,444
LABOUR COST	3 FTE/year	12500 €/FTE/year	€ 37,500
ENERGY COST	67,500 kWh electricity	0.13 €/kWh	€ 8,775
OTHER COSTS	165,761 € total direct costs	10%	€ 16,576
INTEREST ON OPERATING CAPITAL	53,820 € operating capital	8%	€ 4,306
TOTAL COST			**€ 186,643**
BREAKEVEN PRICE (AVERAGE PRODUCTION COST)			**2.36 €/kg**

The cost calculation show that the breakeven price is considerably higher (by 0.41 €/kg) for this system than for the larger system. This means that factors of economies of scale hold more than diseconomies of scale for systems with capacity under 1000 t/year.

[4] HORECA: Hotels, restaurant and cafe (hotel and catering industry)

Advantages and disadvantages associated with larger farm sizes

In the previous section, we calculated the production costs for a farm with 79 t/year capacity and for one with 708 T/year capacity, given certain assumptions. Based on these investors can see how various bio-economic factors affect economies of scale.

The economies of scale exhibited by the larger system can be attributed to:

1. lower labour requirement per unit production[5]
2. lower investment per unit production
3. discounts gained on feed price
4. better energy efficiency due to larger tanks used for production
5. larger farms can perform entire life-cycle farming and do not rely on seed input

However, there are factors of diseconomies of scale, but these are of limited importance in terms of viability:

6. larger farms need to spend more on post-harvest operation (processing, transport, advertisement) to sell their production
7. financial costs of operating capital is higher because the life-cycle is longer (own seed production)

Economies and diseconomies of scale in African Catfish RAS farming

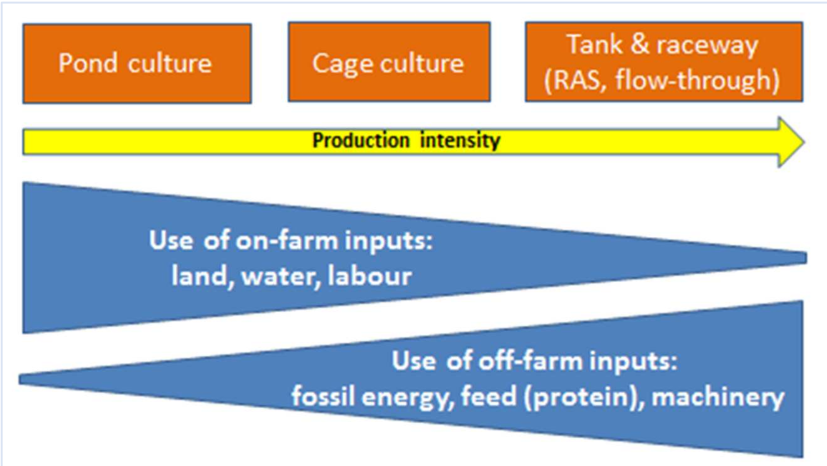
	Cost per unit production (€/kg)	
	79 t/year	708 t/year
Capital costs on Investment	0.24	0.15
Feed Costs	1.07	1.04
Seed Costs	0.20	0.00
Labour cost	0.47	0.14
Energy Cost	0.11	0.08
POST-HARVEST COST	0.00	0.30
Other Costs	0.21	0.17
Interest on operating capital	0.05	0.06
Total Cost	**2.36**	**1.95**

Investors must consider trade-offs between economies of scale and marketing flexibility before deciding on the size of investment. If they know a geographical area where they can profit from fresh market and direct selling to consumers, they can compensate the higher production cost in smaller systems with higher revenues.

[5] 3 persons are needed to run the smaller system, while only 8 persons required to the larger system

Annex I. Relative resource (water, energy) endowments, factor prices.

Fish production is similar to many other similar production processes where inputs are transformed into output such that trade-offs exist between inputs. This means that one can produce a certain amount of fish under extensive conditions by using a certain quantity of feed, equipment, land and water, while it is also possible to produce the same amount of fish under intensive conditions with higher requirement for off-farm inputs (feed, energy, machinery) but lower requirement for land and water. In other words, off-farm inputs can be substituted for on-farm inputs. Usually tank&raceway production systems (RAS and flow-through) require more off-farm inputs and less land, water and labour; while pond systems rely more on on-farm inputs to produce fish. Production systems can also be combined and integrated with one another to exploit synergies, to reduce seasonality or the level of risk.



Within each production system there is also a wide variety of technological alternatives with regard to level of automation in system process; feeding regime; feed quality; fertilization; waste water treatment; stock density; biomass management. These technology factors also determine the intensity of use of different inputs.

Wide variety in input intensity can be illustrated by quantifying the amount of inputs required to produce a certain amount of fish:

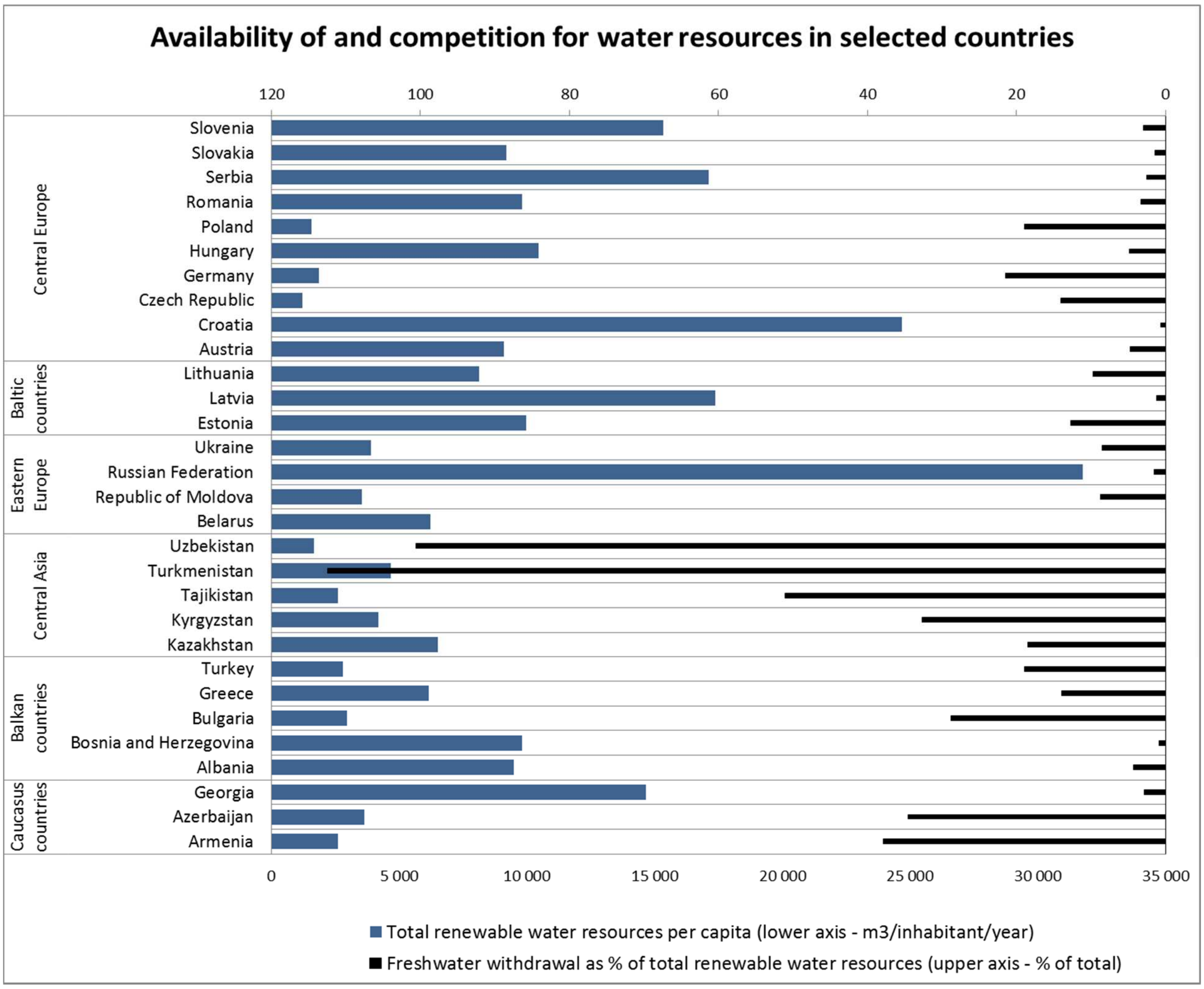
- Water consumption can vary from 0.1 m^3/kg fish to 20 m^3/kg
- Land requirement to establish a 1 kg/year production capacity vary from 0.01m^2 to 20m^2
- External protein requirement to produce 1 kg fish varies from 100 g to 500 g
- Amount of fossil energy to produce 1kg of fish ranges from negligible levels to 2 kWh
- Labour requirement to produce 1 ton of fish varies from 0.1 to 1 person-month

This variety in input usage has a huge implication in cost structure and viability of aquaculture. Heavy reliance on feed results in higher feed costs while reliance on natural processes (extensive farming) results in high land and water costs in total. Similarly, selection of feeding technology has serious implications in production costs: applying a daily feeding rate that minimizes the per-unit feeding costs (minimized Feed Conversion Rate) implies a sub-optimal utilization of production space and high per-unit fixed-costs; while feeding at ad-libitum level maximizes growth rate, increases annual production in the system and reduces per-unit fixed costs but result in increased FCR and per-unit feeding costs. Also, there is trade-off in between machinery&electricity costs and labour costs when deciding about the level of automation in the system. The optimal technology can be determined by bio-economic calculations that are sensitive to factor prices.

The appropriate rearing system for fish production can be selected based on comparative advantages of countries/regions that are resulting from relative resource endowments and from accumulated R&D&I in knowledge-intensive production factors:

- Some countries/regions are abundant in surface/underground water, while others are water-stressed areas. Generally, the cost of water is higher in the latter regions, and there are further administrative restrictions on the use of water. It means that extensive farming technologies can be more profitable in those areas where water is abundantly available and cheap.
- A similar pattern can be seen for the relationship between agricultural land prices and production intensity: extensive technologies are rather suitable farming options in regions where there is not heavy pressure on arable land.
- Feed prices are low in countries where cheap protein sources are available (e.g. agricultural byproducts in Asian countries), and this factor is likely to increase the viability of intensive farming practices.
- Machinery and equipment are products of knowledge-intensive industry, so those countries have comparative advantage in application of machinery where R&D and education is strong in aquaculture engineering. Western countries with high technological background are likely to be more successful in intensive aquaculture than countries which do not invest in technical research.
- In addition, there is a wide variety in wage rates and energy costs between different countries, which influence the choice of production technology. In countries where wage rates are lower, it more viable to invest in labour-intensive technologies.

As an illustration for these considerations, the figure below presents two indices based on which comparative advantages in using water input can be assessed. (The figure contains data for those countries, which are target areas for NARIC HAKI in extension market.) It is shown that in general, countries of Central Europe, Eastern Europe and the Baltic region are more endowed with water while Southern regions (the Balkans, Caucasus and Central Asia) are water-stressed areas, but there are differences between countries within a specific region. Cost of water usually correlates with the quantity available, so there are direct market incentives to apply water-efficient intensive aquaculture technologies in water-stressed regions.



Source: FAO AQUASTAT

Similarly to the characterization of different regions based on factor availability, potential investors' comparative advantages can also be assessed. Such advantages are

- possessing general engineering knowledge; expertise on agricultural mechanics; IT systems;
- having long standing connections with input suppliers; having access to cheap by feed ingredients;
- employing cheap workforce;
- possessing land/water resources otherwise unutilized.

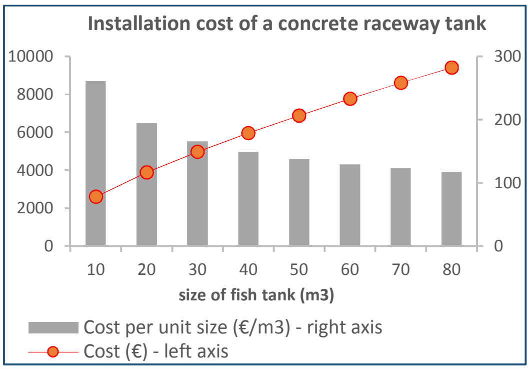
In conclusion, a thorough consideration of available physical and natural capital, workforce, management and engineering skills is needed before making the decision on the production system and technology to be invested in.

Annex II. Recommendation for volume of investment (optimizing the size of the business)

Large aquaculture firms are often more efficient than small ones because they can benefit from economies of scale, but ill-considered large investments may suffer from diseconomies of scale. Once, the investor selects the production technology and the type of rearing system, the next step is to carefully consider the advantages and disadvantages associated with larger and smaller productio facilities. Apart from budgetary constraints, the following factors are worth taking into account when deciding on the volume of investment:

Advantages associated with larger investments (Economies of size):

- *Technical economies:* Cost savings arisen from the use of large-scale production facilities, machinery and operations or more advanced technologies. It can also result from division and specialization of labour. Technical economies may reduce both per-unit investment costs and per-unit operational costs (in other words, both average fixed costs and average variable cost are decreased):
  - o Building larger buildings, ponds, tanks, acquiring larger capacity pumps results in lower investment cost per unit production capacity. The figure illustrates that the installation cost of a 80 m^3 single concrete raceway tank is only 3.6 times more than that of 10 m^3 tank. Ionno (2006)[6] calculated that scaling up a RAS with a production capacity of 20 tons/year to production capacities of 50 tons/year and 100 tons/year would reduce the per unit depreciation cost by 15% and 27%, respectively.



  - o Energy and labour needed to operate the production unit can be used more efficiently when larger tanks/ponds and service equipment are applied.
- *Purchasing economies* are gained when inputs like feed, seed and other consumables are bought in bulk and producers achieve purchasing discounts. Ionno (2006) suggests that when the feed demand of farm is increased from 24 tons/year to 60 and 120 tons/year, 14% and 23% discounts are offered from suppliers on per-unit feed prices.
- Administrative savings can arise as a result of spreading the management costs over a larger production.

Disdvantages associated with larger investments (Diseconomies of size):

- *Markets and marketing costs*: while small-scale farming units can target local retail and HORECA markets, larger producers need to sell their output with higher expenses related to storage, transportation, distribution and product promotion. Larger producer may also have *less responsiveness* to changing market conditions.

[6] De Ionno P. N., Wines G. L., Jones P. L. and Collins R. O. 2006. A bioeconomic evaluation of a commercial scale recirculating finfish growout system – An Australian perspective. Aquaculture 259, pp 315-327.

- *Higher financial exposure:* Larger investments may pose so high risk on producers that sub-optimal decisions are made. Contrarily, small-scale investments can limit financial exposure and have their reason for existence in the own right even without being profitable, as these be conserved as pilot investment on the industry to gain market and operation experience in the beginning before larger facilities are built.
- *Co-ordination problems:* it is much harder to coordinate operations and activities for 50-100 persons than for 5-10 persons. It can also contribute to low motivation of workers in large firms, which may result in lower productivity and decreased output per worker.

The net effect of advantages and disadvantages arising from expansion can partly be assessed by looking at changes in average costs at each stage of production. Average cost is the production cost per unit of output and is calculated by dividing the total costs by the total output, and its unit is €/kg. The firm's long run average cost shows what is happening to average costs when the firm expands.

The reductions in average cost associated with farm expansion are called *economies of size*, and increase in average costs are called *diseconomies of size*. The long run cost curve for most firms is assumed to be 'U' shaped, because of the over a certain production disadvantages associated with market, coordination and financial risk are higher than advantages resulting from technical economies and purchasing economies. The minimum point of long run average cost curves marks the optimal size of the investment.

The figure below illustrates a situation when based on (i) perceived input market and output market conditions and (ii) bio-economic simulations of technical economies, it is estimated that the optimal volume of an investment into pond aquaculture corresponds with the construction of 250-300 hectare large farm. In this example farms larger than 300 ha are exposed to diseconomies of size.