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## **Changing face of central European aquaculture: sustainability issues**

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### **Abstract**

Pond aquaculture is the most significant fish production method in central Europe, approximately 70% of the total fish production is originated from traditional fish ponds in this region, which is a resource-saving, ecologically sustainable production method. However, the growth of this sector is not expected because of the low production capacity of valuable fish species and the relatively high investment cost. A possible solution of the conflict between ecological sustainability, consumer preference and profitability per unit area is the development and application of combined pond fish production systems, which gives opportunity to continue ecologically sustainable and marketable fish production.

**Keywords:** Aquaculture, Europe, Production

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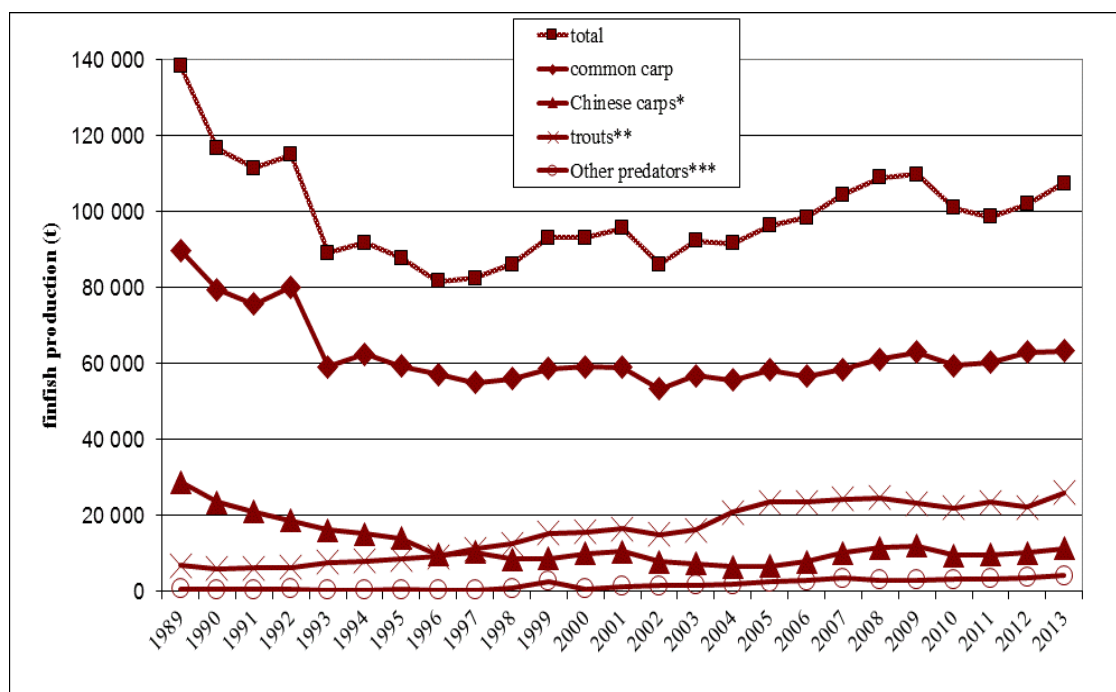
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## Introduction

The global aquaculture production increased by 80% in the last decade (FAO FishStat) due to wide spreading the elements of intensive production technologies (i.e. industrial aquafeeds using, aeration, etc.). Meanwhile the growth rate of aquaculture in the Central European (CE) region (12 countries are involved in this statistics: Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Serbia, Slovakia, Slovenia) was only 16 % between 2003 and 2013. The main produced fish species is common carp in the region; however, its production is stagnating around 60,000 tons, meanwhile the production of Chinese carps is

decreased in the last two decades. However, the production of trout species is exceeded by 250 % of the total production of Chinese carps (Fig. 1).

In this paper we discuss the trends of freshwater fish production and assess its sustainability through ecological and financial criteria in the CE region. The nutrient and natural resources utilisation and environmental impacts of traditional pond culture were assessed and compared with intensive fish production and combined production technologies. After reviewing the fish production characteristics we propose technologies that would make sense to the sustainable aquaculture development in the region.



**Figure 1: Fish production in the CE region.**

\* including silver, bighead and grass carp

\*\* including rainbow trout, brook trout, sea trout

\*\*\* including pike, pike-perch, wels, African catfish

### *Fish production characteristics in*

#### *Central Europe*

##### *Pond aquaculture*

Pond aquaculture is the most significant fish production method in the CE region. Approximately 70% of the total fish production is originated from traditional fish ponds in the region, but there are countries where the ratio of pond aquaculture is even more significant, i.e. Lithuania and Czech Republic more than 90%, Hungary 85 %; Serbia 80%. Production of freshwater fish in manmade ponds is often considered as the oldest fish farming activity in Europe, dating back to medieval times, which are considered a cultural heritage in certain regions, e.g. South Bohemia (Czech Republic), Hortobágy (Hungary) and Lower or Teschen Silesia (Poland) (Adamek et al., 2009). Typical fish ponds are earthen enclosures in which the fish live in a natural-like environment, where a part of the fish gain is originated from the natural food growing in the pond itself (Kestemont, 1995; Bíró, 1995). The common carp giving the majority of production and cultured extensively and semi-intensively can almost be regarded as an organic product as food resources, e.g. zooplankton and zoobenthos found naturally in the pond almost provide the complete nutritional requirements (Adamek et al., 2009). Although the fish yields in the extensive and semi-intensive fishponds are moderate, close to 1000 kg ha<sup>-1</sup> year<sup>-1</sup>, the remarkable part of this yield is originated from the natural productivity of the ponds. Only cereals

and grains are applied as supplementary feed, contributing to 30, 60 and 50% of carp mass gain in the Czech Republic, Hungary and Poland, respectively (Kestemont, 1995; Adamek et al., 2009). However, the market demand for carps as the dominant species in the traditional pond culture is stagnating (Fig. 1.)

##### *Intensive aquaculture*

Simple technologies are applied cages and flow-through systems to produce mainly trout and African catfish in the investigated CE region. Trout production is very significant in Poland but also has a relative large share in the aquaculture production in Czech, Bulgaria, Estonia, Serbia, Romania and Slovakia in flow-through systems, and cages on reservoir lakes in Bulgaria. Flow-through systems using geothermal water are applied for African catfish production in Hungary. Sophisticated indoor recirculation aquaculture systems are not so widespread in the region. Only a few fish production farms are using this technology i.e. sturgeon and barramundi production in Hungary, sturgeon production in Romania.

The intensive culture has adverse effects on the quality of surface waters due to the high nutrient discharge of intensive fish culture, and this kind of production technologies have increased the demand for resources (from one hand more energy, investments needed for the new production systems, and from the other hand more fish meal, fish oil, protein and special feed

ingredients for the predatory fish production). Thus the ecological sustainability of the aquaculture production has been changing even in CE.

**Table 1: Comparison of conventional pond culture and intensive aquaculture.**

	Conventional pond culture	Intensive aquaculture
<b>Place of production</b>	earthen pond	tanks (indoor recirculation and flow-through systems) and cages
<b>Production intensity</b>	0.5-1.5 t/ha on temperate climate	20-300 kg m <sup>-3</sup>
<b>Fish stocking</b>	typically carp-based polyculture	monoculture
<b>Feeding</b>	supplementary grain feeding, typically based on local resources, significant share of natural food (20-50%)	feeding with complete fish feeds
<b>Manuring</b>	typically organic manure application*	-
<b>Energy consumption</b>	low fossil energy consumption	high fossil energy consumption
<b>Trophic level</b>	low (in a range of 2-3.8, average 2.6)	higher (in a range of 3-5, average 3.8)

\* The regulation can be different in different countries in CE, i.e. organic manure using is not allowed in the Czech Republic

### *Sustainability issues*

#### *Environmental concern*

The demand for protection of natural resources has stimulated the development of environmental-friendly aquaculture technologies all over the world. As a consequence, the protection of aquatic environment and the reduction of negative impacts of aquaculture on the environment have become a major concern. Since fish production uses directly the water being one of the most important natural resources, hence in aquaculture development special attention should be given to the innovation of environmental-friendly and water-saving technologies. Various indicators to evaluate the resource use efficiency and sustainability in aquaculture was developed (Boyd, 2005), but the most important issues are to express the nutrient discharge, water consumption, fish meal and oil using to produce 1 kg fish (Bosma and Verdegem, 2011).

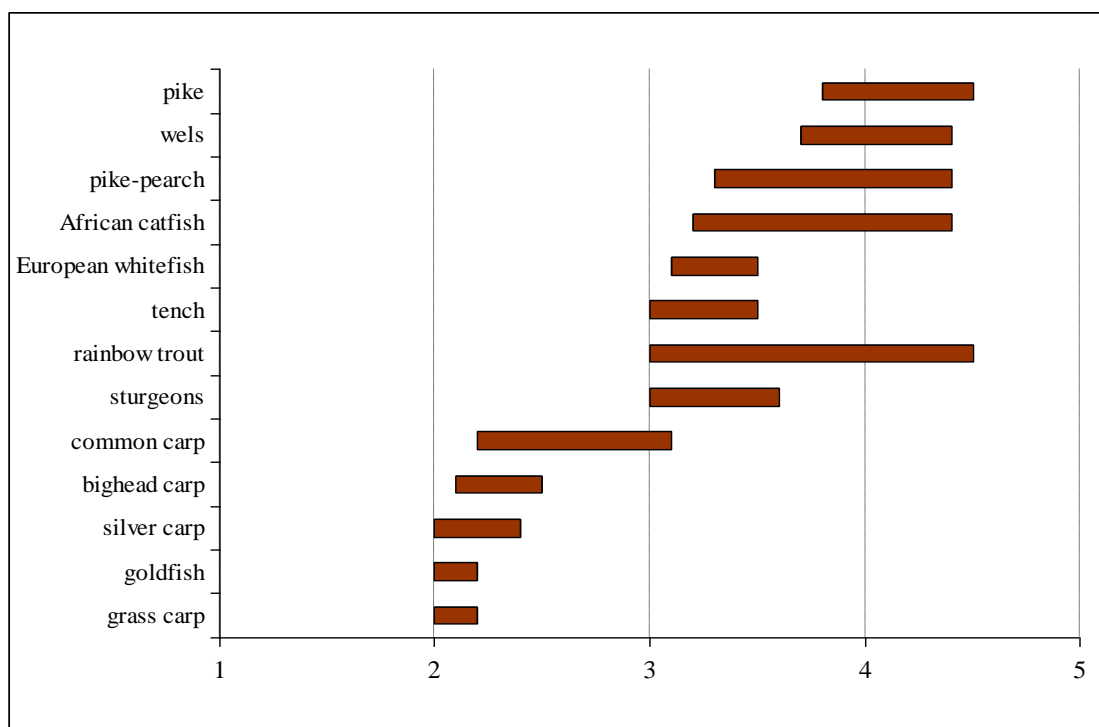
#### *Trophic level and fish meal and fish oil consumption*

Due to the changing consumer preferences the production of predatory fish is increasing in freshwater aquaculture at a global scale but in Central Europe, as well (Fig. 2). The average trophic level of the global freshwater fish production was increased from 2.5 to 2.7 between 1999 and 2009. In CE (involved countries in the study: Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Serbia, Slovakia, Slovenia) the average trophic level of freshwater production is increased slowly from 2.8 to 2.9 in the last decade; however, it was only 2.0 in 1990.

The estimated fish meal and fish oil consumption (FIFO: Fish In to Fish Out ratio) to produce 1 kg freshwater fish in CE region increased from 0.4 (1990) to 1.1 (2000) and 1.5 (2013), because of the increase of predatory species in

intensive culture (i.e. trouts, African catfish), meanwhile the global FIFO was around 0.7 (Tacon and Metain, 2009; Naylor *et al.*, 2010). However, there is no fish meal and oil using in the

traditional pond aquaculture, because the natural food produced in the pond ecosystem is the source of the protein and essential fatty acids.



**Figure 2: Trophic level range for the main fish species produced in CE (source: FishBase).**

### *Nutrient loading*

The environmental impact of fish farm effluents is well-recognised especially in intensive fish farming. Decomposition of both waste feed and fish excreta largely reduces the oxygen content and increases the nutrient concentration in the receiving water, which may result in eutrophication. The main environmental pollutants –the carbon, the phosphorus and the nitrogen– derive from fish feed residuals and fertilisers. Nutrient retention into fish biomass varies only between 20 and 30 % of the introduced

fish feed (Hargraves, 1998; Brune *et al.*, 2003).

The non-retained nutrients by the fish accumulate in the production unit resulting water quality problems. From the water treatment point of view of the fish production systems three different types of systems can be recognised: (1) recirculation systems; (2) flow-through and cage systems and (3) pond systems. In the recirculation aquaculture systems the non-retained nutrients are released from their organic bound and either immobilised in bacterial biomass or volatilised into the atmosphere as gaseous nitrogen and carbon-dioxide.

The main aim during the operation of the recirculation systems is the elimination of the excess nutrients using biofilters in order to improve the water quality for fish production. The water treatment in the recirculation systems requires energy and costly operation of special mechanical and biological filters. During the water treatment, 2/3 part of the valuable nutrients derives from fish feed is lost. The flow-through and cage systems are the most widespread production systems in the intensive fish production in the CE region. Such flow-through systems operating without water treatment unit discharge the majority of input nutrients to the natural waters, leading to eutrophication. In contrast to the previous systems the fishpond allows the recirculation parts of the non-retained nutrients and re-use of nutrients by primary and secondary producers in the pond ecosystem to promote natural food production for fish (Fig. 3).

The nutrient retention capacity of extensive fishponds was described by Oláh *et al.*, 1994; Knösche *et al.*, 2000; Všeticková and Adámek, 2012. A survey was conducted on the water quality of fishponds and to determine the impact of fishponds on the nutrient loads of receiving waters in Hungary (Gál *et al.*, 2008). The retained nutrients represented on average 74% of organic carbon, 53% of nitrogen and 74% of phosphorus introduced into the fishponds. The ratio of organic carbon, nitrogen and phosphorus accumulated

in fish biomass was 6.8%, 18.4% and 10.4%, respectively. The fishponds were found to be able to improve the water quality as 48% and 62% less nitrogen and phosphorus were discharged into the recipient water bodies, respectively. However, 78% more organic carbon was discharged with the effluent from the fishponds, than received with the inlet and supplement water primarily through the increased organic suspended solids concentration in the effluents by the fish production.

The nutrient discharge and utilised nutrients for fish production in various freshwater aquaculture practices are summarised in Table 2. Although the average nutrient utilisation is lower in fishponds comparing to intensive systems the feed-origin nutrient utilisation is higher in pond systems due to its waste reusing potential. The nitrogen and phosphorus discharge for 1 kg fish production is less than half of the intensive systems.

#### *Prospects in the pond aquaculture development*

The precondition of sustainable aquaculture is the efficient use of natural resources and profitable fish production. The traditional pond fish culture is one of those few animal husbandry methods which have minimal deterioration effect on the environment. The majority of the fish production originates from the traditional pond fish production in CE, which is a resources-saving,

ecologically sustainable technology. However, the growth of this sector is not expected because of the relative high investment costs and due to the changing consumer's preference demanding high value mainly predatory fish species produced on external fish feeds in intensive systems. The share of the valuable predatory fish production in pond culture, - which is less than 2% in the traditional pond culture (Adamek *et al.*, 2009) -, should be increased in order to raise the profitability of pond farming and to reduce market disturbances.

According to Adamek *et al.* (2009) the key to future development in pond aquaculture is diversification, either in terms of function, production technology, intensity level or species. The major part of farms should function as extensive pond systems providing ecosystem services to the society, whereas another part of the fish industry will focus on technological development. New combined production systems integrating intensive and extensive pond culture, allowing increased productivity, improved nutrient utilisation and fish species diversification are highly desired.

#### *Combined aquaculture*

A possible solution of the conflict between ecological sustainability, consumer preference and profitability per unit area is the development and application of combined pond fish

production systems, which gives opportunity to continue ecologically sustainable and marketable fish production.

The combination of intensive and extensive aquaculture exploits the advantages of both traditional pond farming and intensive fish culture systems. Valuable predatory fish species can be produced in the intensive part of the system, whilst the integration of an extensive pond as a treatment unit results in decreased nutrient loading to the environment and increased nutrient recovery in fish production (Avnimelech *et al.*, 1986; Diab *et al.*, 1992). Such integrated systems allow the production of diverse fish species without harm to the environment due to the high nutrient retention capacity of extensive fishponds (Oláh *et al.*, 1994; Knösche *et al.*, 2000; Gál *et al.*, 2008). There are already operating combined pond systems in Europe; i.e. combined intensive-extensive pond systems based on the integration of traditional large fishponds and small wintering ponds (Váradi *et al.*, 2001; Gál *et al.*, 2003), as well as in-pond circulation systems where an intensive floating tank is placed into an extensive fishpond (Füllner *et al.*, 2007).

Due to the changing consumers preference the demand for high value mainly predatory fish species is increasing which are produced in intensive systems using external fish feeds.

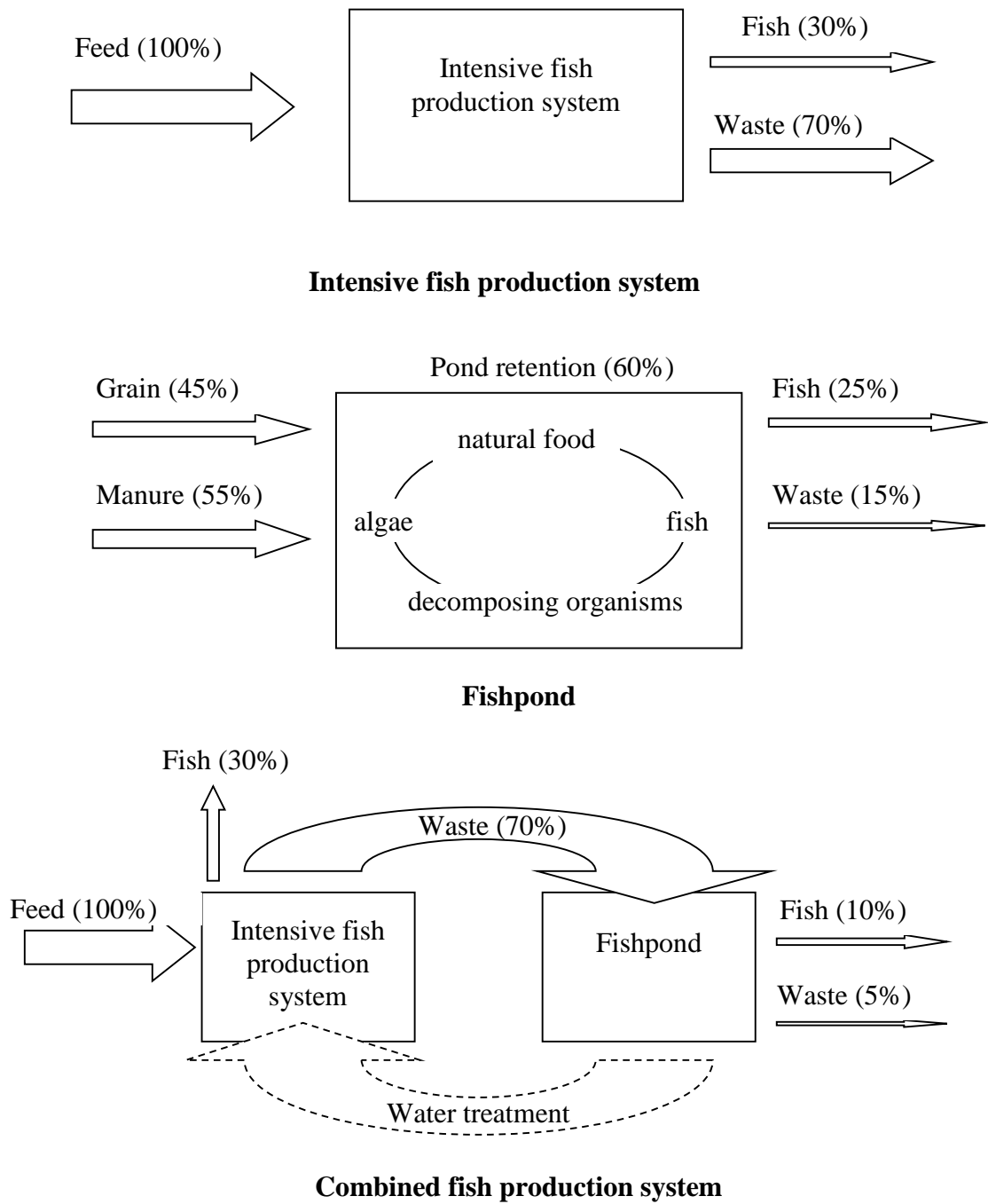


Figure 3: Schematic diagram of the nitrogen cycles of an intensive system, a conventional fishpond and a combined fish production system.



*Case studies of combined fish production*

**Table 2: The relative discharge and consumption of nutrients and water consumption used for fish Production.**

	Fishponds	Combined pond systems		RAS*	Flow-through system**
		Pond recirculation system	Intensive combined system		
<b>Total nutrients used for 1 kg fish production (g kg fish<sup>-1</sup>)</b>					
Nitrogen	120	90	99	74	68
Phosphorus	24	16	16	15	11
Organic carbon	1300	1150	530	440	410
<b>of which feed origin nutrients (g kg fish<sup>-1</sup>)</b>					
Nitrogen	50	55	75	74	80
Phosphorus	7.3	9.9	12	15	13
Organic carbon	975	920	450	440	430
<b>Fish meal consumption for 1 kg fish produced</b>					
FIFO (kg/kg)	0	0.3	1.3	0.4	1.8
<b>Nutrient utilisation of fish production (%)</b>					
Nitrogen	18.4	27.4	33	32	31
Phosphorus	10.4	12.8	32	43	28
Organic carbon	6.8	8.6	21	32	24
<b>Nutrient discharge for 1 kg fish produced (g kg fish<sup>-1</sup>)</b>					
Nitrogen	24	6.4	5.8	46	50
Phosphorus	2.4	1.9	0.53	8.3	6.8
Organic carbon	290	88	48	72	88
<b>Water consumption for 1 kg fish produced (m<sup>3</sup> kg fish<sup>-1</sup>)</b>					
	24	9.7	1.6	0.24	1.1
<b>Energy consumption for 1 kg fish produced (kWh kg fish<sup>-1</sup>)</b>					
	0.2	0.6	0.75	12	0.6

\* data are based on a tilapia RAS system published by Eding *et al.*, 2009

\*\* data are based on an African catfish production flow-through system

*Pond recirculation system – combined system based on traditional fishponds*

The combination of intensive and traditional pond fish farming is a relatively new method for controllable intensive predatory fish production with formulated feed in fishponds.

By exploiting the nutrient processing capacity of the extensive fish ponds with intensive fish production makes possible for the traditional carp farmers to increase their production capacity and diversify the cultured species with the additional intensive fish production. The large

extensive fishpond (the area generally more than 10 ha) gives the majority of the production in this kind of combination. The ratio of the intensive and the extensive fish yields is generally 0.5:1. The share production of intensive part is never exceeding the production of extensive pond.

The investigated combined pond system consisted of five small intensive ponds with total water surface of 1 ha and water depth of 1.5 m, and an extensive treatment pond with a water surface of 20 ha and average water depth of 1.0 m (Fig. 4). The water was

recirculated between the intensive and extensive ponds continuously in the growing season with around 60 days retention time in the extensive treatment pond. The ratio of the water volume of the extensive pond to that of the intensive ponds was 14:1. The average daily water exchange ratio was 11-26 % in the intensive and 2 % in the extensive pond. No effluent water was discharged to the environment during the culture period, the water was only drained from the ponds at fish harvest. Carp based polyculture with 90% common carp and 10% Chinese carps was carried out with supplementary grain feeding in the extensive pond. The main production features of the intensive ponds were the high stocking density and pellet feeding of common carp, African catfish and tilapia, produced in monoculture.

The average nutrient retention in the combined system was 1935 kg ha<sup>-1</sup>

year<sup>-1</sup> for organic carbon, 116 kg ha<sup>-1</sup> year<sup>-1</sup> for nitrogen and 25 kg ha<sup>-1</sup> year<sup>-1</sup> for phosphorus. During the three-year test period 82 % of organic carbon, 62 % of nitrogen and 73 % of phosphorus of the total input were retained by the system of each nutrient. Only a small percentage of the total nutrient input was discharged into the environment during fish harvest. The coefficients of nutrient utilisation by fish were 8.6 % for organic carbon, 27.4 % for nitrogen and 12.8 % for phosphorus (Gál *et al.*, 2003).

A pond recirculation system could be built with relatively low investment at traditional fish farms, where small ponds (wintering ponds) and larger ponds are available by the modification of existing ponds and facilities, through the advantages of intensive production such non-traditional fish production and continuous fish-supply are enforceable.

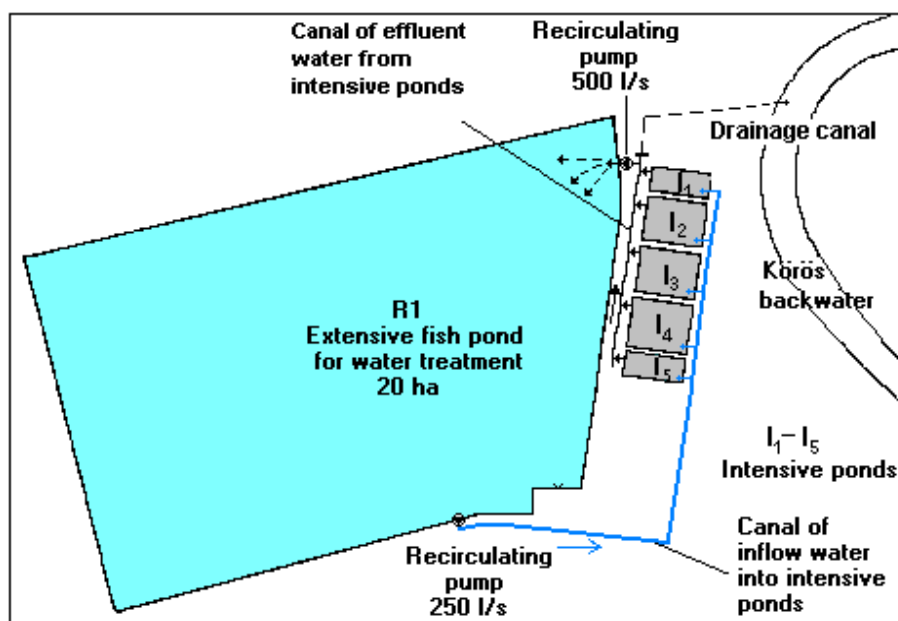


Figure 4: Scheme of the combined intensive-extensive experimental pond system (Váradi *et al.*, 2001)

### *Intensive combined pond system*

The key to the proper operation of such combined systems is the right balance between the nutrient load of the intensive part and the treatment capacity of the extensive pond which can be further extend the application of different technology elements i.e. aeration, water mixing, periphyton, C:N ratio manipulation (Azim, 2001; Gál *et al.*, 2007; Asaduzzaman *et al.*, 2008).

It could be developed a small but highly intensive pond fish production system by the boosting of the biological processes (e.g. anaerobic decomposition, primary production) in fishpond. The intensive combined system can be applied in small ponds (area less than 1 ha) with artificial aeration and water quality management. It is a very promising pond culture method when limited area available for fish production. The ratio of the production of the intensive and extensive parts is 2,5-5:1 in this kind of production method.

The experiments on the intensive combined system were carried out in ponds (area 310m<sup>2</sup>, depth 1m) serving as extensive units, where cages were placed as intensive units (volume 10m<sup>3</sup>) one in each pond. In the intensive units African catfish was cultured and fed with pellet, while common carp was stocked in each extensive unit and raised without any artificial feeding. A paddlewheel aerator was applied in each pond to provide sufficient oxygen concentrations and maintain the water circulation between the intensive and extensive units. The average feed-

originated loads were 2.8 gN m<sup>-2</sup> day<sup>-1</sup>. The aim of this research was to determine the loading capacity of the combined pond systems, evaluate the potential of nutrient reusing and investigate the application of different periphyton density (0, 100 and 200% of the pond surface area) for additional fish production and controlled water quality. According to the results the combination of the intensive and extensive pond production resulted in higher protein utilisation by 22-26%; however with periphyton application this ratio can be increased by 33-45% on average (Gál *et al.*, 2009; Gál *et al.*, 2012).

As a result of controlled water quality and nutrient recycling the overall fish yields in combined intensive-extensive systems are higher than in traditional pond fish production systems. The net yields of the traditional fishponds are usually below 1 t ha<sup>-1</sup>; however, the yields of pond recirculation systems are 3-5 t ha<sup>-1</sup> and the intensive combined systems 20 t ha<sup>-1</sup>. The application of the combined production system contributes to the ecological sustainability diversifies the produced fish species and multiplies the overall production intensity. Although there are limits of the water treatment in extensive fishpond; i.e. the treatment efficiency is affected by the temperature and a relatively large pond area is needed to process the waste from intensive production (Table 3).

**Table 3: Advantages and disadvantages of combined fish production systems**

<b>Advantages</b>	<b>Disadvantages</b>
Simple technology with low investment and operation costs	Less controllable production conditions (i.e. temperature)
Higher nutrient utilisation capacity due to the extensive fish production	The water quality is resulted from the biological processes in pond
Low nutrient discharge	Limited production season (April till October in Hungary)
Low energy demand	The winter storage of fish need to be solved
Lower water consumption comparing the traditional pond culture	
Due to the concentrated production in small area the fish can be protected better from predators	

### *Effluent treatment in constructed wetland*

Majority of intensive fish production originated from flow-through systems operating without appropriate water treatment in CE. The combination of intensive systems (flow-through and conventional RAS without phosphate removal and denitrification unit as well) with constructed wetland is a cost effective and feasible solution to increase the environmental sustainability of this kind of aquaculture practice. Most of the flow-through African catfish production farms in Hungary have been operating recently with the combination of constructed wetlands to improve the quality of discharged water and to reduce payment of environmental loading fee.

The investigated pilot-scale constructed wetland system was also built for the treatment of the effluents of an intensive flow-through African catfish farm in Szarvas (Hungary). The surface-flow wetland systems were constructed from four serially connected ponds as a combination of a stabilisation pond, a fishpond (1.5 m

deep) and two macrophyte ponds (0.5 m deep, covered by cattail and reed) with the total area of 1.1 hectare. The effluent from the African catfish farm was channelled into the aerated stabilisation pond, where a paddle wheel aerator was operated and supplement river water was added. The water from the stabilisation pond was introduced into the fishpond unit, where a certain part of nutrients were retained in fish biomass (Kerepeczki *et al.*, 2003; Kerepeczki *et al.*, 2005; Gál *et al.*, 2009).

The operation of the constructed wetland system was characterized by effective nutrient removal efficiency and additional revenue possibilities. The combination of a stabilisation pond, a fishpond and macrophyte ponds enhanced the nutrient removal efficiency since the different wetland types were able to remove different nutrient forms. The nutrient removal of the wetland system was on average, 1,130, 100 and 3,000 kg ha<sup>-1</sup> year<sup>-1</sup> for nitrogen, phosphorus and organic carbon, respectively. The efficiency of water treatment exceeded the 90 % removal rate for nitrogen and organic

carbon, and 79 % for phosphorus. Since there is a seasonality in the water treatment, its efficiency and loading capacity is highly depend on the temperature (Table 4). On average, 4.8 % of the total input of nitrogen and 10% of the phosphorus input were reutilised in the by-products (fish and

energy plants). 1200-1500 kg ha<sup>-1</sup> fish (mainly silver, common and bighead carp) were produced only with the utilisation of the natural food growth on the wastewater.

**Table 4: The loading capacity of constructed wetland at different temperature intervals.**

Water temperature interval	N loading	P loading		COD loading
		kg ha <sup>-1</sup> day <sup>-1</sup>		
10-15 °C	3.0	0.4		19
15-20 °C	5.7	0.4		31
20-25 °C	7.4	0.8		44

The traditional pond fish production is one of the ecologically most sustainable fish production methods, although the growth of the fish production of this sector is not expected, because of the limited marketability of carp species. To exploit the production capacity existing in pond culture there is a need to diversify the produced fish with the intensive rearing of valuable species.

The combined production systems integrating intensive and extensive pond culture, allowing increased productivity, improved nutrient utilisation and fish species diversification together with saving the environmentally sound character of pond culture.

The precondition of sustainable aquaculture is the efficient use of natural resources, profitable fish production and contributions of aquaculture to employment of the rural population. The traditional pond fish production is a resource-saving, ecologically sustainable production

method, however the growth of this sector is not expected because of the low valuable fish production capacity and the relatively high investment costs. Due to the changing consumers preference the demand for high value - mainly predatory fish species - is increasing which are produced from intensive systems using external fish feeds. A possible solution of the conflict between ecological sustainability, consumer preference and profitability per unit area—is the development and application of combined pond fish production systems which gives opportunity to continue ecologically sustainable and marketable fish production.

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