University of Debrecen
Centre of Agricultural Sciences
Faculty of Agricultural Sciences
Department of Animal Husbandry

Doctoral School of Animal Husbandry

Leader of Doctoral School: Prof. Dr. Sci. András Kovács

Supervisors:

Dr. László Pócsi
C.Sc.

Dr. László Váradi
Ph.D.

„THESIS OF DOCTORAL (Ph.D.) DISSERTATION"

DEVELOPMENT OF ENVIRONMENTAL FRIENDLY COMBINED POND FISH PRODUCTION TECHNOLOGIES

by
Dénes Gál

Debrecen
2006

I. INTRODUCTION, BACKGROUND AND RELEVANCE OF THE STUDY

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 the 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 aqauculture development special attention should be given to the innovation of environmental friendly and water saving technologies.

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; AVNIMELECH, 2005).

Only a small part of the nutrient content of fish feed is utilised by fish production.

The non-retained nutrients accumulate in the production unit resulting water quality problems. From the point of view of water treatment 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 bio filters in order to improve the water quality for fish production. The water treatment in the recirculation system 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-though systems are the most widespread production systems in the intensive fish production in Hungary. 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 for fish.

The intensive fish production in tanks has become widespread in the last fifteen years in Hungary. The effluent treatment of these intensive systems hasn't been solved properly. 21,000 tons fish is produced in aquaculture systems in Hungary. Nine percent of the total fish production comes from intensive systems (PINTÉR, 2005). The 1800 tons intensively produced fish was mainly originated from flow-trough systems in 2004. According to my estimation approximately 700 tons of organic matter, 100 tons of nitrogen and 30 tons of phosphorus are discharged by the fish production from flow-through systems into the natural waters every year.

The expected growth of the volume and intensity of fish production and the new environmental legislation made necessary the development and application of new and environment-friendly aquaculture technologies. Considerable efforts are being made for minimising the negative impact of fish farm effluents on the environment, such as the use of recirculation systems with biofilters, the application of wetland systems and sedimentation ponds, and special equipment for effluent treatment. The aquatic ecosystems, some including fishponds have a growing role in the treatment of effluents from intensive agriculture. Several international and Hungarian research projects proved that the natural and constructed aquatic ecosystems are able to treat communal and agricultural sewage (LAKATOS, 1998; VYMAZAL, 2001). Integrated pond systems have a long tradition in Asia. In an integrated pond system, waste serves as nutrient for fish production generating additional profit for farmers (CHANG, 1987; NACA, 1989; LIU and CAI, 1998).

NAYLOR et al. (2000) summarised the necessary steps for the sustainable fish production as follows: expansion of the farming of low trophic level fish; reduction of fish meal and fish oil inputs in feed; development of integrated farming systems; and promotion of environmentally sound aquaculture practices and resource management. Whereas due to the changing consumer preferences, the production of valuable high quality carnivorous fish in intensive systems fed with artificial feed is increasing.

During the development of environmental friendly fish production technologies it seems to be obvious solution that the effluent from intensive aquaculture is treated in a fishpond ecosystem or intensive aquaculture is integrated with fishpond systems. In the course of effluent treatment in a fishpond the excess nutrients are removed by biological processes and a part of the nutrients are converted into fish flesh. The principle of the investigated method is to treat the effluent water enriched with organic and inorganic nutrients of intensive fish ponds in an extensive pond. In the extensive pond, a part of the nutrients is utilised through various biological production processes and their other part is fixed in the pond sediment, and the water treated or purified is recycled to the intensive fishponds. The application of the combined production system contributes to the ecological sustainability and production of marketable fish.

II. OBJECTIVES OF THE STUDY

Aim of my present work was to develop integrated, environmental friendly fish production technologies, which are suitable for the processing and reusing of the excess nutrients from intensive fish culture. In my present work the nutrient cycling and environmental impacts of traditional pond culture were assessed and compared with two integrated production technologies. In the first case such kind of combined system was investigated where the effluent from intensive fish production were utilised in an extensive fishpond ecosystem directly. The other integrated system was developed for the purification and re-use of effluent water from intensive fish production in combined algal pond and fishpond units.

By the combination of different aquaculture production systems the water demand and nutrient loading to the environment can be decreased, whilst the nutrient recovery for fish production increased. During the course of my study I evaluated the nutrient utilisation in the production systems, and investigated the interaction of fish production systems and their surrounding natural environment, towards increasing the recovery of applied nutrients into fish meet, according to the followings:

- Survey the water quality of fishponds, and determine the impact of fishponds on the nutrient loads of receiving waters and evaluate the nitrogen, phosphorus and organic matter budget of the fishponds representing different technologies and geographic areas.
- Describe the water and sediment quality and evaluate the water purifying capacity of the Combined Intensive-Extensive Pond System through the analysis of the organic carbon, nitrogen and phosphorus budgets in a three-year-long experiment.
- Survey of the water quality of the Combined Algae-Aquaculture System in a pilot scale experiment.
- Compilation and comparison of the nutrient budget of the investigated production systems, evaluation of nutrient recovery and discharge.

III. MATERIALS AND METHODS

Description of the investigated systems

Survey on the environmental impact of pond aquaculture

The investigations were carried out on water, sediment and production parameters of 23 fishponds. The fishponds operated with semi-intensive, carp based polyculture and supplementary grain feeding technologies, which is typical in Hungary. Fishponds are represented different technologies, sizes and areas of the main carp producing regions (Észak-Alföld (Northern Great Plain), n=6; Közép-Alföld (Central Great Plain), n=4; Dél-Alföld (Southern Great Plain), n=4; Dunántúl (Trans Danubia), n=9) were taken into investigated.

The technological parameters of the ponds (stocking, harvesting, feeding and manuring) were summarised by the pond register. Nitrogen, phosphorus and organic carbon content of the sediment and the filling-up and effluent water were determined by laboratory analysis.

Study of the combined intensive-extensive pond production system

The pilot scale investigations were carried out between 1999 and 2001. The investigated fish pond recirculation system consists 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. 1). The water was recirculated between the intensive and extensive ponds with around 60 days retention time in the extensive treatment pond. During the operation of the system effluent water of the intensive ponds was collected in a drainage canal, where it was pumped into the 20 ha extensive treatment pond. The treated water from the extensive pond was pumped back into the intensive ponds. Ratio of the water volume of the extensive pond to that of the intensive ponds was 18:1 in 1999 and 13.5:1 in 2000 and 2001. No effluent water was discharged to the environment during the culture period, the water was only drained from the ponds at fish harvest. The evaporation was regularly compensated in the extensive pond during the experimental period.

Carp based polyculture with 90% common carp (*Cyprinus carpio*) and 10% Chinese carps, i.e. silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Aristichthys nobilis*) 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 (*Cyprinus carpio*), African catfish (*Clarias gariepinus*) and tilapia (*Orechromis niloticus*), produced in monoculture.

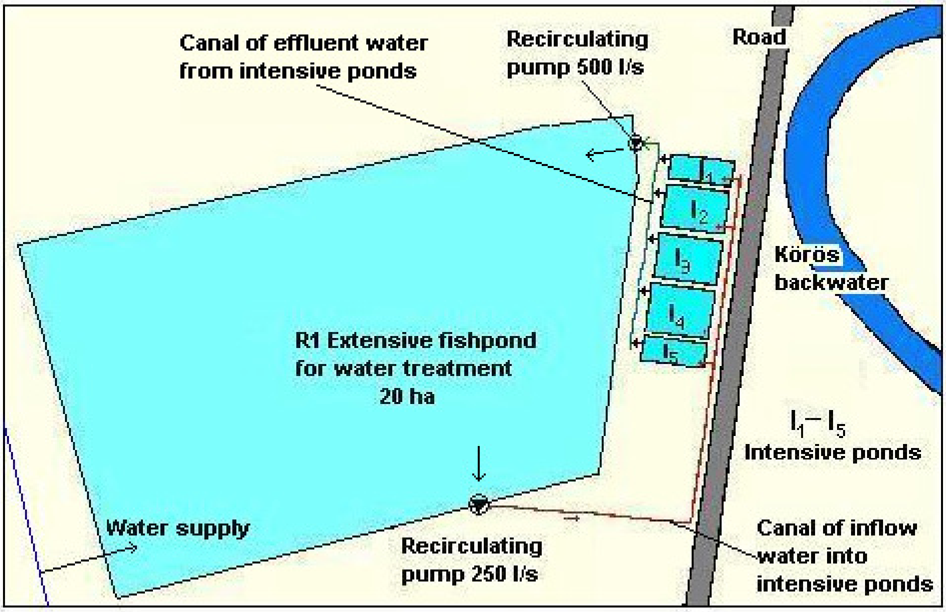

Figure 1 *Scheme of the combined intensive-extensive pond fish production system (HAKI, Szarvas, Iskolaföld)*

The daily water exchange ratio varied between 3 and 53 % in the intensive ponds, 0.65 and 3.6 % in the extensive treatment pond. The average daily water exchange ratio was 11-26 % in the intensive and 1.8 % in the extensive pond.

The volumes of filling-up, make-up and recirculated water were monitored throughout the experimental period, and discharged water was measured at harvest. The whole water column was sampled monthly at the inlets and outlets of the ponds, and the samples were analysed for nutrient concentrations. Nutrient concentrations of the filling-up and make-up water were also determined, when they were supplied.

During the three-year long investigated period the sediments of all ponds were sampled three times a year: spring, in the middle of the growing season and after harvesting.

Study of the combined algae-fishpond effluent treatment system

The possibilities of treatment and reuse of intensive fish culture effluents in a combined algae-fishpond system were investigated in 2004. The combined pilot scale experimental system consisted of three different compartments: tanks for intensive fish production, an algal pond where the excess nutrients were removed by algae production, and a fishpond where the produced algae biomass was consumed by fish (Figure 2).

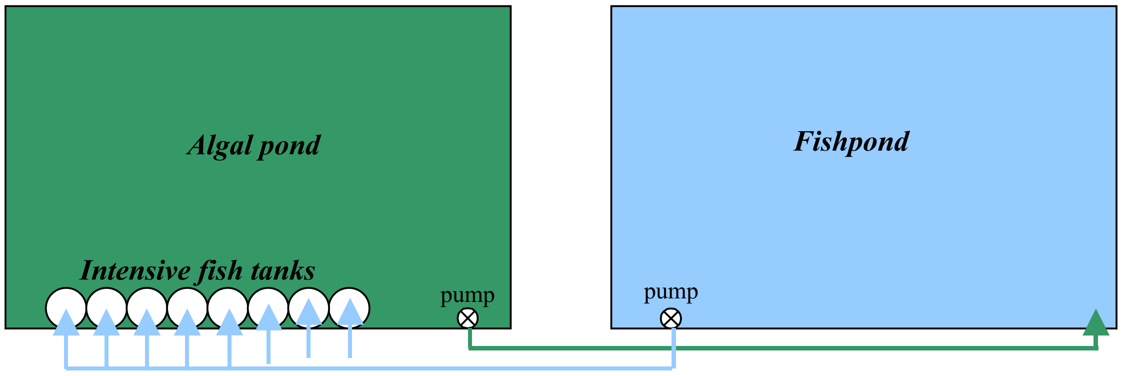

***Figure 2** Scheme of the combined aquaculture-algae system (HAKI, Szarvas)*

The total volume of the fish tanks was 8 m^3. The water depth was 0.6 and 1m in the algal and fishpond units, respectively. The water surface area was 150 m^2 of the algal and fishpond unit, each. The water depth was 0.6 and 1m in the algal and fishpond units. The ratio of water volume of the intensive fish tanks, algal pond and extensive fishponds was 1:11:19. The system was operated as a closed system, no effluent water was discharged to the environment during the culture period, and the water was only drained from the ponds at fish harvest. The evaporation and seepage were regularly compensated in the extensive fishpond. During the operation of the system effluent water of the intensive fish tanks flowed into the algal pond directly, the water from the algal pond was pumped into the extensive fishpond. The treated water from the fishpond was pumped back into the intensive fish tanks. The hydraulic retention time was 0.1, 1.9 and 3.2 day in the intensive fish tanks, the algal pond and the fishpond, respectively.

African catfish (*Clarias gariepinus*) was produced in the fish tanks with intensive pellet feeding; its stocking density was 50 kg m^{-3}. Common carp (*Cyprinus carpio*) and Nile tilapia (*Oreochromis niloticus*) were stocked into the fishpond without feeding, and the stocking density was 0.38 and 0.24 kg m^{-3}, respectively. There was no fish stocking in the algal pond. The fish were fed with pellets (protein content 47.5 %) in the intensive fish tanks the feeding ratio was 1.5 %. There was no feeding in the extensive fishpond.

For the high productivity of algal pond continuous mixing was applied. For water mixing a submerged pump (1 kW) was installed in the algal pond. The water transparency measured with Secchi disk varied between 15 and 20 cm in the algal pond. The velocity of water circulation was 10-15 cm s-1.

The volumes of filling-up and make-up and flow rate of recirculated water were monitored throughout the experimental period, and discharged water was measured at harvest. The whole water column of each part of the system was sampled twice a week during the experiment, and the samples were analysed for ammonia-, nitrite- and nitrate-nitrogen, soluble reactive phosphorus, volatilise suspended solids, biochemical oxygen demand and chlorophyll-a.

Methods of analysis

Nutrient budgets:

Nutrient removal, retention and discharge of the system, the quantity of total organic carbon, total nitrogen and total phosphorus of inputs (fish feed, stocked fish, supplying water) and that of outputs (harvested fish, effluent water) were estimated and the nutrient budgets were calculated. The partial nutrient budget was calculated using mass balance equation, based on the concept (KNÖSCHE et al., 2000; SCHNEIDER et al., 2005):

Nretained = (Ninflow + Nfish stocked + Nfish feed) – (Nfish harvested + Noutflow)

where N is the nutrients content of the given source.

Nutrient budget of the inlet and outlet water (nutrient-water budget/net discharge):

For the description of the effect of production systems on the surrounding environment the nutrient-water budget was calculated from the difference the nutrient content of the inlet and effluent water.

Nutrient retention in fish biomass:

The proportion of the retained nutrients by fish production (net yield) in the total nutrient input was calculated according to the following:

$$TH\,(\%) = \frac{TA_{HALKI} - TA_{HALBE}}{TA_{BE}}\ x100$$

where TH: nutrient retention in fish biomass

TA_{HALKI}: nutrient content of the harvested fish

TA_{HALBE}: nutrient content of the stocked fish

TA_{BE}: total introduced nutrients

IV. THE MAIN STATEMENTS OF THE STUDY

Survey on the environmental impact of pond aquaculture

The investigated fishponds were able to retain high amount of nutrients. The retained nutrients represented on average 74 % of organic carbon, 53 % of nitrogen and 74 % of phosphorus introduced into the fishponds.

In the fishponds, the ratio of organic carbon, nitrogen and phosphorus accumulated in fish biomass was 6.8 %, 18.4 % and 10.4 %, respectively.

By the estimation of the environmental impacts of the investigated fishponds it can be stated that the fishponds were able to improve the water quality, as 48 % and 62 % less nitrogen and phosphorus were discharged into the recipient water bodies, respectively. However 78±126 % 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.

There were large differences between the nutrient budget of the inlet and outlet water among the various fish ponds. According to our studies, it was found that the nitrogen content of the effluent water depends on nitrogen concentration in the sediment. In that ponds where the nitrogen concentration was extremely high in the sediment the nitrogen concentration in the effluent at drainage were higher than in the intake water, as well.

There was no any relationship between the production intensity and the nutrient content in the effluent, hence it can be stated that the production intensity can be increased without serious impact on natural waters.

Our observations proved the pond fish culture is one of those few animal husbandry methods which has no deterioration effect on the environment. Moreover during the pond production of fish flesh – which has a proven health promotion effect on the human nutrition – excess nutrients discharged from other animal husbandry units can be utilised in fish ponds. In the pond culture excess nutrients are converted into harvestable products results in reduced waste discharge and protection of the natural resources.

Contrarily to intensive animal husbandry and intensive aquaculture the pond culture allows the use of renewable natural resources. Using proper pond management practises and built on the processes in the pond ecosystem, economical fish production can be carried on whilst minimising the nutrient discharge into the natural waters protecting this way the natural environment.

Study of the combined intensive-extensive pond production system

The pilot scale experiment, which has been carried out in a 21 ha combined intensive-extensive fish pond system proved the applicability of such systems in farming conditions. Investigations on the nutrient budget of the system demonstrated that an adequate size extensive fishpond with sufficiently long water retention time could treat the effluent from intensive fishponds efficiently and make possible to reuse the water for intensive fish production. Investigations on the organic carbon, nitrogen and phosphorus budgets revealed that relatively large ratio of nutrient inputs is utilised by the fish cultivated in the extensive pond, a part is accumulated in the sediment and another part is decomposed in the ponds and released to the atmosphere.

The average nutrient retention in the combined system was 1935 kg ha^{-1} $year^{-1}$ for organic carbon, 116 kg ha^{-1} $year^{-1}$ for nitrogen and 25 kg ha^{-1} $year^{-1}$ 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. As a result of controlled water and nutrient recycling the overall fish yield of combined intensive-extensive system are higher than in a traditional pond fish production system operated under similar climatic conditions in Hungary. The application of the combined intensive-extensive pond fish production system could contribute to the better use of water resources and to the protection of the environment.

The combined intensive-extensive system incorporates the advantages of the intensive and pond fish culture. The intensive unit is suitable for fish production of valuable fish species (African catfish, tilapia, sturgeons, wells, and carp) in high stocking density. The main technological feature in the extensive unit is the application of the carp based poli- or biculture which results in higher fish yields than in conventional pond culture. The combined system can be constructed by the utilisation of existing fishponds (wintering ponds and their water supply facilities, growing ponds).

Study of the combined algae-fishpond effluent treatment system

The retained nutrients represented 62 % of the organic carbon, 57 % of the nitrogen and 77 % of the phosphorus introduced into the combined aquaculture system. The combined system could remove larger amount of nutrients (3.2 % for organic carbon, 9.3 % for nitrogen and 13.1 % for phosphorus) than the traditional fishponds and combined intensive-extensive production system.

The harvested fish represented 31.9 % of organic carbon, 41.0 % of nitrogen and 15.5 % of phosphorus on the percentage of the total introduced nutrients.

For the high productivity of algal pond continuous water mixing was applied. The mixing is important to ensure that all cells are kept in suspension in the water column and exposed regularly to light to avoid the self shading effect of dense algae cultures. The pilot scale experimental combination of an intensive fish production unit, a high-rate algal pond and an extensive fishpond proved the applicability of such systems. The combined system could process a significant part of surplus nutrients from the intensive fish production. Investigations on the nutrient budget of the system demonstrated that an adequate size algal and extensive fish pond with sufficiently long water retention time could treat the effluent from intensive fish culture efficiently and make possible the reuse of water for intensive fish production.

In the operation of water treatment systems besides algae nutrient uptake, bacterial decomposition, consumption of heterotrophic organisms and denitrification processes has significant role. Hence, the regulation of oxygen regime, to provide aerobic condition by artificial aeration is important for the efficient nutrient removal during water treatment.

Further researches are needed to enhance the algae and bacteria biomass consumption and the nutrient recovery by fish; there is a demand for new technological solutions and feeding experiments with fish species focused on microbial biomass consumption.

Contrary to controlled conditioning sewage treatment system the natural based water treatment is affected by the changable natural condition. Further researches are needed to answer the influence of light intensity and temperature on the rate of nutrient process in order to determine the effect of the seasonal variation and the changing of weather conditions on the efficiency of water treatment. More research are also needed to determine the effect of C:N:P ratio on the water treatment efficiency.

The amounts of utilised and discharged nutrients by the fish production system are summarised in the Table 1.

Table 1. The utilised and discharged nutrients of fish production and water consumption of the investigated systems

	Fishponds	**Combined Intensive-Extensive System**	**Combined Algae-Aquaculture System**
Utilised nutrients to produce 1 kg fish (g kg fish biomass^{-1})			
Nitrogen	120±37.9	90.4±15.45	69.7
Phosphorus	24.1±22.5	16.0±1.40	15.7
Organic carbon	1318±341	1146±107	374
Utilised fish food nutrients to produce 1 kg fish (g kg fish biomass^{-1})			
Nitrogen	50.1±14.9	55.1±5.66	49.9
Phosphorus	7.29±1.76	9.91±2.13	6.94
Organic carbon	975±233	922±61.4	291
Discharged nutrients by 1 kg produced fish (g kg fish biomass^{-1})			
Nitrogen	23.7±27.1	6.35±3.01	0.68
Phosphorus	2.40±2.66	1.86±1.57	0.56
Organic carbon	289±388	87.9±45.7	23.5
Water consumption to produce 1 kg fish (m^3 kg fish biomass^{-1})			
	24.3±14.2	9.67±2.35	1.28

V. NEW SCIENTIFIC RESULTS

1. The nitrogen, phosphorus and organic matter input into the examined fish production systems and their relative nutrient retention were calculated. The examined traditional fishponds retained 53 % of the total input nitrogen, 74 % of the input phosphorus and 74 % of the input organic carbon. The combined intensive-extensive pond production system retained 62 % of the total input nitrogen, 73 % of the input phosphorus and 82 % of the input organic carbon. The combined algae-fishpond system retained 57 % of nitrogen 77 % of phosphorus and 62 % of organic carbon.

2. The examined fish production systems were compared according to the aspect of the environmental effect on the recipient waters. It was found that from the fishponds with the effluent water 43 and 62 % less nitrogen and phosphorus were discharged respectively, and at the same time 78 % more organic carbon, than received with the inlet and supplement water. It was pointed out that there was no correlation between the quality of the discharged water and the harvested fish biomass. According to the comparisation of the inflow and effluent nutrient amounts, it was found that 59 and 37 % less nitrogen and phosphorus, and more than 3 times higher amount of organic carbon were discharged from the combined intensive-extensive pond production system, than it received. The quality of the drainage water in the combined system was different from the above mentioned intensive-extensive system and the traditional fishponds, because of the high nutrient load. The amounts of discharged nutrients with the effluent water were in the matter of organic carbon 14 times, in the matter of nitrogen 4 times and in the matter of phosphorus 3 times higher than those of the inlet water.

3. It was found that by the combination of the intensive and the extensive fish production technologies the amount of retained nutrients in fish biomass can be enhance. It was demonstrated that in the fishponds, the ratio of nitrogen, phosphorus and organic carbon retained in fish biomass was 18.4 % and 10.4 % and 6.8 %, respectively. In the combined intensive-extensive pond production system 27.4 % of the total input nitrogen, 12.8 % of the input phosphorus and 8.6 % of the input organic carbon, was recovered in fish biomass. In combined

algae-fishpond system 41.0 % of the total input nitrogen, 15.5 % of the input phosphorus and 31.9 % of the input organic carbon was recovered in harvested fish biomass.

4. It was found that the primary production was significantly higher in the combined algae-fishpond system received large amounts of nutrients and operated with continuous water mixing than the combined intensive-extensive pond production system. The ratio of the average gross primary production was 3.1 g C m^{-2} day^{-1} in the combined intensive-extensive pond production system and 14.8 C m^{-2} day^{-1} in combined intensive-extensive pond system. The ratio of the organic carbon bounded by primary production accumulated in fish biomass growth were 5.1 % in the extensive pond of the combined intensive-extensive pond system and 5.8 % in the fishpond of the combined algae-fishpond system.

5. For the examined fish production systems, the specific nutrient amounts used for production of live fish biomass and the specific nutrient discharge by produced fish biomass were calculated. It was found that for the production of 1 kg fish yield in average 1328 g organic carbon, 120 g nitrogen and 14 g phosphorus were utilised in the studied traditional fishponds, while with the effluent water 289 g organic carbon, 24 g nitrogen and 2.4 g phosphorus were discharged in average. In the combined intensive-extensive pond system, for the production of 1 kg fish yield 1146 g organic carbon, 90 g nitrogen and 16 g phosphorus were utilised. From the combined intensive-extensive pond system, in average 88 g organic carbon, 6.3 g nitrogen and 1.9 g phosphorus were discharged during the production of 1 kg fish biomass. In the combined algae-fishpond system for 1 kg fish production 374 g organic carbon, 70 g nitrogen and 16 g phosphorus were applied, while with the effluent water in average 24 g organic carbon, 0.7 g nitrogen and 0.6 g phosphorus were discharged from the system. The specific nutrient amounts used for fish production and discharged with the effluent water of the combined algae-fishpond system were significantly lower than those of traditional pond fish production or the combined intensive-extensive pond system.

VI. UTILISATION OF THE RESULTS IN PRACTICE

The combination of intensive and extensive fishpond technologies with water recirculation resulted in significant reduction of nutrient discharge to the surrounding aquatic environment. The combined system was able to ensure the required water quality for fish production and made possible the reuse of water for intensive fish production and the recovery of excess nutrients by extensive pond culture. The efficiency of nutrient retention can be improved by the partition of the treatment pond to an algal and a fishpond unit.

The effluents from intensive fish production systems can also be treated in extensive fishponds, where the excess nutrients are removed by biological processes and a part of the nutrients are converted into fish flesh. According to the examinations of nutrient dynamics it was concluded that 1 ha extensive fishpond area is able to treat the effluent from 5-6 tons intensively produced fish.

Combined systems could be built with relatively low investment at traditional fish farms, where small 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. The wider scale application of sustainable and environmental friendly fish production technologies are supported by the Fisheries Operative Program and European Fisheries Fund.

By the additional fish production in the extensive fishpond the nutrient recovery into fish biomass increases and the nutrient discharge into the recipient waters decreases. The reused surplus nutrients by the additional fish production can enhanced the nutrient utilisation in fish flesh by 5-10 %. The efficiency of water treatment can be improved by application different technological interventions like artificial aeration or water mixing.

The long term protection of natural resources is an important element of sustainable fish production. The using of the combined fish production systems makes possible the high intensity production without environmental impact. The application of combined systems meets the requirements both of the ecological and economical sustainability:

- marketable fish production on economical way,
- environmentally sound fish production and resources management using mainly renewable natural resources,

- the farming of the low trophic level fish has a significant role in the combined system, these fish are able to produce valuable fish protein from the excess “waste” nutrients discharged from the intensive production unit, thereby increase the nutrient recovery in the fish flesh.

VII. PUBLICATIONS IN THE FIELD OF DISSERTATION

Peer reviewed publications

- **GÁL D.**, SZABÓ P., PEKÁR F., VÁRADI L. (2001): Kombinált intenzív-extenzív tavi haltermelő rendszer működésének tápanyagforgalmi tapasztalatai. Hidrológiai Közlöny. 81. 5-6. 364-366. p.
- **GÁL D.**, SZABÓ P., PEKÁR F., VÁRADI L. (2003): Experiments on the nutrient removal, retention and discharge of a pond ecosystem. Hydrobiologia. 506. 1. 767-772. p.
- KEREPECZKI É., **GÁL D.**, SZABÓ P., PEKÁR F. (2003): Preliminary investigations on the nutrient removal efficiency of a wetland-type ecosystem. Hydrobiologia. 506. 1. 665-670. p.
- **GÁL D.**, KEREPECZKI É., SZABÓ P., PEKÁR F. (2003): Halastavak környezeti terhelésének vizsgálata: nitrogénmérleg és nitrogén kibocsátás. Hidrológiai Közlöny. 83. 1-12. 52-54. p.
- KEREPECZKI É., **GÁL D.**, PEKÁR F. (2003): Kombinált halastó/wetland vízkezelő rendszer működésének tapasztalatai. Hidrológiai Közlöny. 83. 1-12. 71-73. p.
- **GÁL D.**, KEREPECZKI É., PEKÁR F., VÁRADI L. (2005): Environmental issues in Hungarian aquaculture and recent research on sustainable fish production. Lucrări Ştiinţifice Zootehnie Şi Biotehnologii. 38. 500-505. p.
- **GÁL D.**, LEFLER K.K., RÓNYAI A. (2005): Effect of temperature on the sexual maturation of pike-perch (*Sander Lucioperca* L.). LARVI'05 European Aquaculture Society Special Publication 36. 160-163. p.
- **GÁL D.**, SZABÓ P., PEKÁR F., KEREPECZKI É., VÁRAI L. (2005): Tápanyag-visszatartás és eltávolítás vizsgálata egy integrált tavi rendszerben. Agrártudományi Közlemények. 16. 18-23. p.
- **GÁL D.**, RÓNYAI A., VÁRADI L. (2005): Kombinált alga-hal vízkezelő rendszer működésének tapasztalatai. Hidrológiai Közlöny. 85. 6. 35-37. p.
- **GÁL D.**, KEREPECZKI É., SZABÓ P., PEKÁR F. (2006): A tógazdasági haltermelés környezeti hatásainak felmérése. Agrártudományi Közlemények. 21. 19-24. p.
- **GÁL D.**, PEKÁR F., KEREPECZKI É., VÁRADI L. (2006): Experiments on the operation of the combined aquaculture-algae system. Aquaculture International. (in press)
- PAPP, ZS. GY., PEKÁR, F., KEREPECZKI É., **GÁL D.** (2006): Natural-origin off-flavours in fish related to feeding habits. Water Science and Technology. (in press)

Full publications in proceedings of international and Hungarian conferences

- VÁRADI L., **GÁL D.**, SZABÓ P., KOVÁCS GY., VALENTINYI K., PEKÁR F. (2000): Kombinált intenzív-extenzív tavi recirkulációs rendszer működésének tapasztalatai, különös tekintettel a tápanyagforgalomra. A XXIV. Halászati Tudományos Tanácskozás, Haltenyésztési Kutató Intézet, Szarvas, 2000. május 24-25., Halászatfejlesztés, 24: 39-46. p.
- **GÁL D.**, SZABÓ, P., PEKÁR, F. AND VÁRADI, L. (2002): Development of a combined intensive-extensive pond fish production system for the sustainable use of natural resources. International Conference of Young Researchers, Ukrainian Academy of Sciences, Kiev, Ukraine, Feb. 22-28 2002, Abstract book, 8-10. p.

- **GÁL D.**, PEKÁR F., SZABÓ P., VÁRADI L. (2002) Kombinált intenzív-extenzív tavi recirkulációs rendszer fejlesztése a természeti erőforrások fenntartható használatáért. Innováció, a tudomány és a gyakorlat egysége az ezredforduló agráriumában, Debreceni Egyetem Mezőgazdaságtudományi Kar, 2002. április 11-12., Környezetvédelem, természetvédelem, 5-10. p.
- **GÁL D.**, PEKÁR F., SZABÓ P., VÁRADI L. (2002): Környezetbarát haltermelő rendszer fejlesztése. III. Alföldi Tudományos Tájgazdálkodási Napok, Tessedik Sámuel Főiskola Mezőgazdasági Főiskolai Kar, Mezőtúr, 2002. október 17-18., Termeléstechnológia Vol. 2. 175-177. p.
- KEREPECZKI É., **GÁL D.**, PEKÁR F. (2002): Intenzív halnevelő telepek elfolyó vizének kezelése halastavak és vizes élőhelyek alkalmazásával. A XXVI Halászati Tudományos Tanácskozás, Halászati és Öntözési Kutatóintézet, Szarvas, 2002. május 8-9., Halászatfejlesztés 27. 32-39. p.
- VÁRADI L., BÉKEFI E., **GÁL D.** (2003): Combined Extensive-Intensive Pond Fish Production System for the Sustainable Use of Natural Resources. International Symposium "Cold Water Aquaculture: Start in the XXI Century", Ministry of Agriculture of the Russian Federation, Sept. 8-13 2003, Saint-Petersburg, Russia, Reports and Abstracts, 37-38. p.

Abstracts in proceedings of international conferences

- **GAL, D.**, SZABO, P., PEKAR, F., VARADI, L. (2001): Development of a combined intensive-extensive pond recirculation system. 37th Croatian Symposium on Agriculture, 19-23 February 2001, Opatija, Croatia.
- **GÁL, D.**, SZABÓ, P., PEKÁR, F., VÁRADI, L. (2002): Experiments on the nutrient removal, retention and discharge of a pond ecosystem. Shallow Lakes 2002: International Conference on Limnology of Shallow Lakes, 25-30. May 2002, Balatonfüred, Hungary.
- **GÁL, D.**, SZABÓ, P., PEKÁR, F., VÁRADI, L. (2002): Development of a combined intensive-extensive pond fish production system for the sustainable use of natural resources. International Conference of Young Researchers, Ukrainian Academy of Sciences, 25-28 February 2002, Kiev, Ukraine.
- **GÁL, D.**, RÓNYAI, A. (2002): Oxygen consumption, growth and food conversion of young Nile tilapia fed with different diets. International Symposium on Nutrition and Feeding in Fish, 2-7 Jun 2002, Rhodos, Greece.
- KEREPECZKI, É., **GÁL, D.**, SZABÓ, P., PEKÁR, F. (2002): Preliminary investigations on the nutrient removal efficiency of a wetland-type ecosystem. Shallow Lakes 2002: International Conference on Limnology of Shallow Lakes, 25-30 May 2002, Balatonfüred, Hungary.
- KEREPECZKI, É., **GÁL, D.**, PEKÁR, F. (2002): Studies on the utilisation of discharged nutrients from an intensive fish production plant. International Symposium on Nutrition and Feeding in Fish, 2-7 Jun 2002, Rhodos, Greece.
- **GÁL, D.**, PEKÁR, F., VÁRADI, L. (2002): Development of a water saving and environmental-friendly pond fish production system. 3nd National Scientific and Professional Conference with International Participation, 20-21 June, 2002, Bizovac, Croatia.
- **GÁL D.**, PEKÁR F., VÁRADI L. (2003): Combined intensive-extensive pond fish production system for the sustainable use of natural resources. Aquaculture Europe-2003 „Beyond monoculture", 8-12 August 2003, Trondheim, Norway.

- VÁRADI, L., BÉKEFI, E., **GÁL, D.** (2003): Combined extensive-intensive pond fish production system for the sustainable use of natural resources. International Symposium, "Cold water aquaculture: Start in the XXI century", St. Petersburg, Russia, September 8-13, 2003.
- RÓNYAI, A., **GÁL, D.**, KOVÁCS, E. (2003): Propagation of pike-perch (Stizosteidon lucioperca) under controlled conditions. Percis III. The Third Percid Fish International Symposium, Madison, Wisconsin, USA, July 20-24, 2003.
- **GÁL, D.**, PEKÁR, F., VÁRADI, L. (2004): Reducing environmental impacts of intensive fish production by integration with a high-rate algal pond and an extensive fishpond. Aquaculture Europe 2004. „Biotechnologies for quality", Barcelona, Spain, October 20-23, 2004.
- **GÁL D.**, PEKÁR F., KEREPECZKI É., VÁRADI L. (2005): Waste treatment and reuse of intensive fish production in pond recirculation systems. New Challenges in Pond Aquaculture, České Budějovice, Czech Republic, April 26 – 28, 2005.
- **GÁL D.**, LEFLER K.K., RÓNYAI A. (2005): Effect of temperature on the sexual maturation of pike-perch (Sander Lucioperca L.). LARVI'05 Fish and Shellfish Larviculture symposium, Ghent, Belgium, September 3-7.

<u>Abstracts in proceedings of Hungarian conferences</u>

- VÁRADI L., **GÁL D.**, SZABÓ P., KOVÁCS GY., VALENTINYI K., PEKÁR F. (2000): Víztakarékos és környezetbarát tavi haltermelő rendszer fejlesztése: Kombinált intenzív-extenzív tavi recirkulációs rendszer működésének tapasztalatai. XXIV. Halászati Tudományos Tanácskozás, Haltenyésztési Kutató Intézet, Szarvas, 2000. május 24-25.
- **GÁL D.**, SZABÓ P., PEKÁR F. ÉS VÁRADI L. (2000): Kombinált intenzív-extenzív tavi haltermelő rendszer működésének tápanyagforgalmi tapasztalatai. XLII. Hidrobiológus Napok, Tihany, 2000. október 4-6.
- **GÁL D.**, SZABÓ P., PEKÁR F., VÁRADI L. (2002): Kombinált intenzív-extenzív tavi haltermelő rendszer fejlesztése a természeti erőforrások fenntartható használatáért. Tessedik Sámuel Jubileumi Mezőgazdasági Víz- és Környezetgazdálkodási Tudományos Napok, Tessedik Főiskola Mezőgazdasági Víz- és Környezetgazdálkodási Főiskolai Kar, Szarvas, 2002. augusztus 29-30.
- KEREPECZKI É., **GÁL D.**, PEKÁR F. (2002): Intenzív halnevelő telepek elfolyó vizének kezelése halastavak és vizes élőhelyek alkalmazásával. XXVI. Halászati Tudományos Tanácskozás, Halászati és Öntözési Kutatóintézet, Szarvas, 2002. május 8-9.
- **GÁL D.**, KEREPECZKI É., SZABÓ P., PEKÁR F. (2002): Halastavak környezeti terhelésének vizsgálata: nitrogénmérleg és nitrogén kibocsátás. XLIV. Hidrobiológus Napok, Tihany, 2002. október 2-4.
- KEREPECZKI É., **GÁL D.**, PEKÁR F. (2002): Kombinált halastó-wetland vízkezelő rendszer működésének tapasztalatai. XLIV. Hidrobiológus Napok, Tihany, 2002. október 2-4.
- **GÁL D.**, SZABÓ P., PEKÁR F., VÁRADI L. (2002): Környezetbarát haltermelő rendszer fejlesztése. III. Alföldi Tudományos Tájgazdálkodási Napok, Mezőtúr, 2002. október 17-18.
- RÓNYAI A., **GÁL D.** (2003): Előzetes adatok a tápon nevelt fogassüllő növekedéséről és takarmány-hasznosításáról. XXVII. Halászati Tudományos Tanácskozás, Halászati és Öntözési Kutatóintézet, Szarvas, 2003. május 7-8.

- **GÁL D.**, RÓNYAI A., VÁRADI L. (2004): Kombinált alga-hal vízkezelő rendszer működésének tapasztalatai. XLVI. Hidrobiológus Napok, Tihany, 2004. október 6-8.
- **GÁL D.**, SZABÓ P., PEKÁR F., KEREPECZKI É., VÁRADI L. (2004): Tápanyag-visszatartás és eltávolítás vizsgálata egy integrált tavi rendszerben. Tudományos Napok, Debreceni Egyetem, 2004. november 15.
- **GÁL D.** (2005): Kombinált tavi termelő rendszerek fejlesztése. 73. Országos Mezőgazdasági és Élelmiszeripari Kiállítás (OMÉK), Fiatal Agrárkutatók Fóruma, Budapest, 2005. szeptember 1.

Other publications

- VÁRADI L., **GÁL D.**, PEKÁR F., SZABÓ P. (2001): Combined Extensive-Intensive Pond Fish Production System for the Sustainable Use of Natural Resources. Hungarian Agricultural Research. 10. 2. 13-15. p.
- **GÁL D.** (2003): The effect of retention time on the nutrient removal in a high rate algal pond. Reserch Report. Wageningen University, Wageningen, The Netherlands. 51. p.
- **GÁL D.**, KEREPECZKI É., SZABÓ P., PEKÁR F. (2002): A tógazdasági haltermelés környezeti hatásainak felmérése különböző haltermelési technológiák alkalmazása mellett. Kutatási jelentés, Halászati és Öntözési Kutató Intézet, Szarvas, 33. p.
- **GÁL D.**, XINTHUA, Y. (2005): A kínai édesvízi akvakultúra fejlődése. Halászat. 98. 4. 156-160. p.