Arch. Pol. Fish.	Archives of Polish Fisheries	Vol. 10	Fasc. 2	187-205	2002

THE INTENSIFICATION OF POND FISH PRODUCTION AND THE MAGNITUDE OF THE WASTE LOAD DISCHARGED DURING AUTUMN HARVESTING

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ABSTRACT. Carp were cultivated in polyculture with grass carp, silver carp and European catfish. The chemical parameters (pH, oxygen, ammonia nitrogen, nitrate nitrogen, nitrite nitrogen, total nitrogen, phosphates, total suspensions, chemical oxygen demand COD_{Mn}) of discharged water and four pond layers were measured during the autumn harvest. The study indicated that when the water was discharged the amounts of nitrogen compounds, phosphates and especially total suspension increased from 40 mg dm^{-3} in the first layer to 152 mg dm^{-3} in the last layer and that chemical oxygen demand COD_{Mn} increased from 10 mg dm^{-3} in the first layer to 176 mg dm^{-3} in the last layer. The results of both physical and chemical tests on the water discharged from ponds during two periods of the autumn harvest were used to calculate the magnitudes of the loads of organic matter, total suspension and nutrients. The loads of organic matter (expressed as COD_{Mn} in an acidic medium), nitrogen, phosphorus and suspensions in the discharged water were determined per ha of area. The highest values were observed in T-type ponds (1,500 specimens ha^{-1}) at an average of 1,214 kg ha^{-1} and in G3-type ponds (4,000 specimens ha^{-1}) with an average of 1,198 kg ha^{-1}. This data allowed the chemical parameters (kg ha^{-1}) of waters discharged from the ponds in autumn to be compared with the level of COD_{Mn} and the amount of nutrients which are introduced to the ponds in spring, as well as to determine the degree of nutrient and organic matter retention in the pond. In the majority of cases nitrogen is fully retained, phosphates are either fully or partially retained and there is an increase in water chemical oxygen demand COD_{Mn} especially during the harvest in September.

Key words: COMMON CARP (*CYPRINUS CARPIO*), INTENSIVE CULTURE, POND, HYDROCHEMICAL PARAMETERS OF WATER, WASTEWATER, RETENTION

INTRODUCTION

The aim of cultivating carp in ponds is to achieve significant production in the shortest time feasible by optimizing the applied production technology. Fish grow fast when they have the proper amount of food available to meet their needs. Natural food in ponds fulfills this requirement, but its limited resources do not allow for highly efficient production to be achieved. Therefore, the production sites which employ extensive or low intensity methods do not pose a significant threat to the reservoirs which receive their post-production waters, and they can also be used to treat third-degree wastewater as they effectively eliminate nutrients (Iwaszkiewicz and

Madziar 1979, Kosturkiewicz et al. 1993). Intensifying pond fish cultivation by increasing the stock density and feeding them large quantities of feed does not only impact the environmental conditions of the pond (Lewkowicz and Kolasa-Jamińska 1982, Kolasa-Jamińska 1994), but it also impacts the quality of the water discharged from the ponds during harvesting. The current poor state of surface water purity is a growing problem for many users of these waters, including fish farms. Recently it has become the norm in most western European countries to allow fish cultivation provided it does not have an adverse impact on water quality. Some scientists are of the opinion that at some point the natural significance of fish ponds will outweigh their cultivation role (Lymbery 1992). Concern for the natural environment, especially about the purity of surface waters, has led to the imposition of requirements regarding the physical and chemical parameters that both the input and output waters of the ponds should have. Water quality in the ponds varies during the production season, and the scale of these changes depends on the amount and quality of fertilizers and fish feed used. This, in turn, impacts the magnitude of production. In every fisheries pond complex the loads in the post-production waters discharged into reservoirs depend on the purity of the used water, the fish species and the production methods.

The aim of the study was to determine the organic matter and nutrient loads in post-production waters and to compare these values with the amount of organic matter (expressed in water chemical oxygen demand COD_{Mn}) and nutrients which are introduced into the ponds when they are filled, and, finally, to determine the degree of retention of these components.

MATERIAL AND METHODS

The study was conducted at the Institute of Ichthyobiology and Aquaculture, PAS, Gołysz. The facility is located in the foothills of the Beskid Śląski near Ziemia Cieszyńska (southern Poland) on an accumulation plateau of the Vistula River at an altitude of 270 m above sea level. The Goczałkowicki Reservoir is located 7 km below the output from the ponds, which greatly limits the possibility of intensive fish production in these ponds (Wróbel 1998). The study was conducted in the Gołysz pond complex which is comprised of ponds with identical areas and depths. Carp $K_{2\text{-}3}$ were cultivated in a polyculture with grass carp *Ctenopharyngodon idella* (Val.), silver carp *Hypophthalmichthys molitrix* (Val.) and European catfish *Silurus glanis* L. Table 1 presents an outline of the study. In 1995 and 1996, the first and second years of the study, the

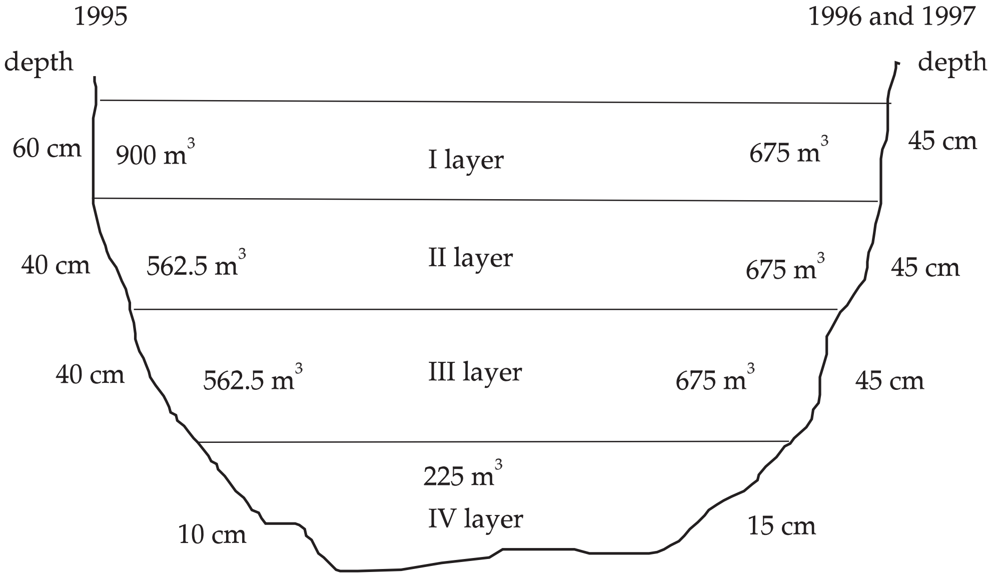

Fig. 1. Pond layers of varying depths and capacities according to study year.

discharged water from 12 ponds was tested; six ponds, one of each stock density variant, were tested in September and the following six in November. In 1997, the discharged water from 21 ponds was tested; 14 ponds, two from each pond stock density variant, were tested in September and seven in November (one from each pond stock density variant). Each of the studied ponds was divided into four layers of a known volume and depth which were determined along the outlet box (Fig. 1). Water samples of 1 dm^3 each were collected from each layer at a fixed station (the pier next to the outlet box) with a bathometer. The first sample was collected from the surface water layer of full ponds. After the upper layer of water had been drained, the next water sample was collected and the next water layer was drained. The last sample was collected from the 10 (1995) or 15 cm (1996 and 1997) water layer. Total pond volume was 2,250 m^3.

The purity of the water discharged during the harvest was evaluated based on dissolved oxygen content, pH, total suspension, ammonia nitrogen, nitrate nitrogen, nitrite nitrogen, chemical oxygen demand (COD_{Mn})using the permanganate method (permanganate value) and phosphates. With the exception of oxygen content, the other parameters were determined using standard methods according to Hermanowicz et al. (1976).

TABLE 1

Study scheme, 1995-1997

Year	Pond variant	Fish stock (specimens ha $^{-1}$) and fish generations				Feed
		Carp	Grass carp	Silver carp	European catfish	
1995		K_{2-3}	Ab_{1-2}	Tb_{2-3}	Se_{2-3}	
	O	0	0	0	0	None
	PN	500	100	200	67	Natural food
	T	1,500	333	600	67	Grain feed
	G1	1,500	333	600	867	Granulated feed
	G2	4,000	800	1,600	867	Granulated feed
	G3	4,000	800	1,600	867	Granulated feed
1996		K_{2-3}	Ab_{2-3}	Tb_{3-4}	Se_{1-2}	
	O	0	0	0	0	None
	PN	500	100	200	67	Natural food
	T	1,500	333	600	67	Grain feed
	G1	1,500	333	600	633	Granulated feed
	G2	4,000	800	1,600	633	Granulated feed
	G3	4,000	800	1,600	633	Granulated feed
1997		K_{2-3}	Ab_{2-3}	Tb_{2-3}	Se_{2-3}	
	O	0	0	0	0	None
	PN	500	100	153	100	Natural food
	T	1,500	300	453	0	Grain feed
	G1	1,500	300	453	0	Granulated feed
	G2	4,000	800	1,200	0	Granulated feed
	G3	4,000	800	1,200	220	Granulated feed
	G4	4,000	800	1,200	220	Extruded feed

Variant description:
O - pond without fish
PN - stock size calculated according to natural output
T - semi-intensive cultivation, stock size calculated for grain feed
G1 - semi-intensive cultivation; stock size and production intensity determined for granulated feed (32.5% protein, 13% fat)
G2 - intensive cultivation, stock size determined for granulated feed (32.5% proteins, 13% fat)
G3 - intensive cultivation, stock size determined for granulated feed (32.5% proteins, 13% fat) and water aeration at the peak of the season
G4 - intensive cultivation, stock size determined for extruded feed (36% proteins, 22% fat)

In order to determine the degree of pollution of the post-production waters which were drained in autumn from the fish ponds, it was necessary to determine the chemical parameters of both the discharged and input water per ha of area. The values of the chemical parameters for discharged waters from the four layers were summed and recalculated from mg dm^{-3} to kg ha^{-1}. The loads of organic matter, nutrients and suspended matter were calculated per unit of area. The studied pond complex is supplied with water from the Młynówka Kiczycka River, a right-bank tributary of the Vistula River. The chemical characteristics of the supply water have been continuously analyzed for more than twenty years, and samples for the current study were collected directly at the inflow point to the ponds. The results of the author's own studies (Kolasa-Jamińska, unpublished data) which constitute an average of analyses that were carried out during three spring periods (one directly before and two during pond filling) are presented in Table 2a. In order to determine the magnitude of post-production water pollution, it was necessary to recalculate the results of the chemical analyses of the supply water from mg dm^{-3} to kg ha^{-1} (Table 2b).

TABLE 2a

Supply water chemical parameters (mg dm^{-3})

Parameter	Year		
	1995	1996	1997
COD_{Mn}	6.16	4.92	6.13
$N\text{-}NO_2 + N\text{-}NO_3 + N\text{-}NH_4$	2.99	2.43	1.23
$P\text{-}PO_4$	0.417	0.375	0.155

The results obtained over the course of three years were analyzed statistically in order to confirm the significance of differences in chemical parameters (permanganate value, total suspension, ammonia nitrogen, phosphates) between particular water layers. The NIR test was applied (significance level $\alpha = 0.05$).

TABLE 2b

Supply water chemical parameters (kg ha^{-1})

Parameter	Year		
	1995	1996	1997
COD_{Mn}	61.5	49.2	61.2
$N\text{-}NO_2 + N\text{-}NO_3 + N\text{-}NH_4$	30.0	24.2	12.3
$P\text{-}PO_4$	4.1	3.7	1.5

In order to more fully describe the impact fish production magnitude has on the water chemistry in ponds as well as on the quality of water discharged from these ponds, the magnitude of fishery production by year is included in the paper (Table 3a, b, c).

TABLE 3a

Fish production in ponds in 1995

Pond variant	Carp stock		Carp harvest		Growth ($kg\ ha^{-1}$)	Survival rate (%)	Feed amount ($kg\ ha^{-1}$)
	spec. ha^{-1}	kg ha^{-1}	spec. ha^{-1}	kg ha^{-1}			
September							
PN	500	213	340	426	213	68	0
T	1,500	420	633	946	526	42	1,732
G1	1,500	460	713	952	492	48	3,037
G2	4,000	1,339	1,672	2,717	1,378	42	6,920
G3	4,000	1,399	2,045	3,630	2,231	51	7,699
November							
PN	500	190	320	406	216	64	0
T	1,500	440	859	1,172	732	57	2,048
G1	1,500	460	886	1,572	1,112	59	3,563
G2	4,000	1,352	1,905	3,044	1,692	48	6,807
G3	4,000	1,319	2,511	3,989	2,670	63	7,199

TABLE 3b

Fish production in ponds in 1996

Pond variant	Carp stock		Carp harvest		Growth ($kg\ ha^{-1}$)	Survival rate (%)	Feed amount ($kg\ ha^{-1}$)
	spec. ha^{-1}	kg ha^{-1}	spec. ha^{-1}	kg ha^{-1}			
September							
PN	500	166	420	420	254	84	0
T	1,500	473	1,499	1,379	906	100	3,403
G1	1,500	313	1,718	2,511	2,198	100	3,922
G2	4,000	1,059	3,476	3,516	2,457	87	7,493
G3	4,000	999	3,457	3,330	2,331	87	7,606
November							
PN	500	130	493	260	130	99	0
T	1,500	313	1,305	1,505	1,192	87	3,703
G1	1,500	313	1,252	2,131	1,818	84	3,929
G2	4,000	999	3,683	3,064	2,065	92	7,546
G3	4,000	1,119	3,643	3,576	2,457	91	8,398

TABLE 3c

Fish production in ponds in 1997

Pond variant	Carp stock		Carp harvest		Growth ($kg\ ha^{-1}$)	Survival rate (%)	Feed amount ($kg\ ha^{-1}$)
	spec. ha^{-1}	$kg\ ha^{-1}$	spec. ha^{-1}	$kg\ ha^{-1}$			
			September				
PN	500	167	480	326	159	95	0
T	1,500	523	1,399	1,818	1,295	93	4,875
G1	1,500	310	1,119	1,312	1,002	75	4,229
G2	4,000	1,365	2,711	3,516	2,151	68	8,964
G3	4,000	1,405	3,949	4,675	3,270	99	10,010
G4	4,000	1,459	3,703	4,828	3,369	93	7,539
			November				
PN	400	270	373	446	176	93	0
T	1,200	773	1,145	1,778	1,005	96	3,903
G1	1,200	753	1,059	1,692	939	88	4,975
G2	2,665	1,652	2,451	4,069	2,417	92	9,397
G3	2,665	1,578	2,031	3,710	2,132	76	10,742
G4	2,665	1,578	2,278	4,316	2,738	85	8,365

RESULTS

THE NUMBER OF PARAMETERS STUDIED IN FOUR LAYERS OF THE DRAINED PONDS

The discharged water was alkaline, and its pH in September varied from 7.0 to 8.5 and in November from 7.0 to 8.0. In all cases the lowest water pH was observed in layer IV. Oxygen saturation in the various water layers varied from 40 to 100%. In both September and November the lowest saturation values (10% and below) were observed in the near bottom layer.

The highest total suspension concentrations during both harvest periods were recorded in water layer IV (Fig. 2). As the water was drained from the subsequent layers, the quantity of total suspension increased to the point that they were two-fold higher in the near bottom layer than in the upper layers. The amounts of suspension in September were lower than in November. The amount of organic matter in layers I-III, expressed as the permanganate value in an acidic environment, was low and varied in the range of 0 - 10.0 mg O_2 dm^{-3} (Fig. 2). Its highest values were observed in the last layer of water drained from the ponds.

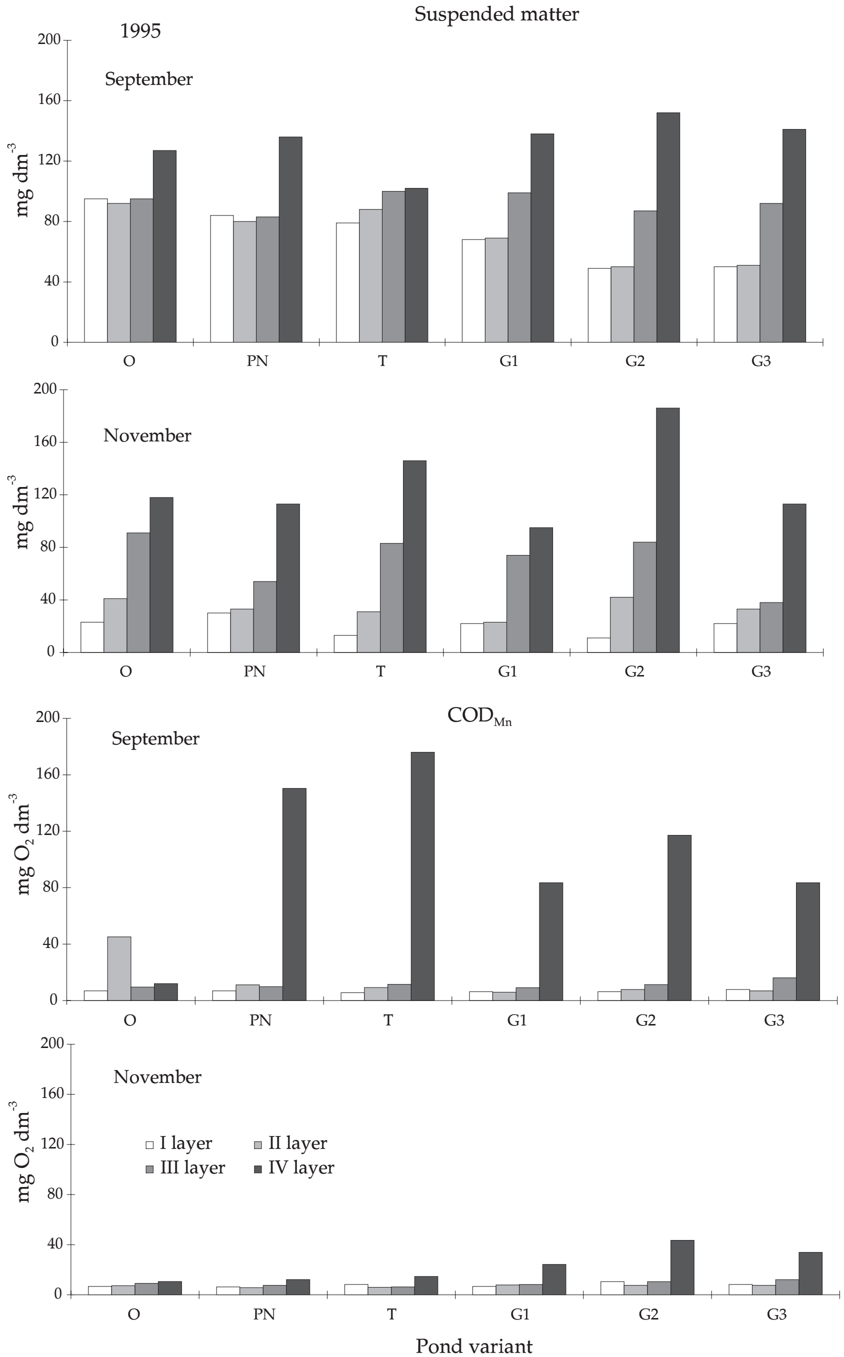

Fig. 2. Suspended matter amount and chemical oxygen demand COD_{Mn} value in the different water layers of the drained ponds.

Concentrations of ammonia nitrogen were low in drained layers I – III and varied from 0.5 to 2.0 mg N-NH4 dm^{-3} (Fig. 3). Water layer IV had the highest concentrations of this form of nitrogen, and in September 1996 very high values of it were observed at 14.0-15.0 mg N-NH4 dm^{-3}. The amount of N-NH4 grew as the stock densities increased (this was especially apparent in November) and reached a maximum value of 9.20 mg N-NH4 dm^{-3} in a pond with the highest cultivation intensity. The levels of this nutrient in the drained waters in November were significantly lower. The highest concentrations of nitrate and nitrite nitrogen were observed in the final stage of water discharge (IV) when their levels were sometimes ten-fold higher than those in water layer I. The amount of phosphates in water layers I and II were low and did not exceed 0.250 mg P-PO4 dm^{-3} (Fig. 3). The amounts of phosphates in other water layers were from two- to three-fold (layer III) and ten- to twelve-fold higher (layer IV).

The data in Table 4 show that there was a statistically significant difference in total suspensions between layers I and II and layers III and IV. Statistically significant differences were observed for other chemical parameters (COD_{Mn}, ammonia nitrogen and phosphates) between layers III and IV.

TABLE 4

NIR test of the determined parameters

Layer	Parameter			
	Suspended matter	COD_{Mn}	$N\text{-}NH_4$	$P\text{-}PO_4$
I	53.0^a	8.15^a	1.07^a	0.31^a
II	70.8^b	9.88^a	1.17^a	0.40^a
III	82.5^b	12.32^a	1.48^a	0.55^a
IV	112.0^c	29.72^b	3.44^b	1.10^b

Parameter values in columns with the same letter index do not vary statistically, P > 0.05

MAGNITUDE OF ORGANIC MATTER, NUTRIENT AND SUSPENSION LOAD AND INDICATORS OF THE BALANCE OF CHEMICAL OXYGEN DEMAND COD_{Mn}

STUDY I – 1995

In September the lowest load of organic matter was observed in pond G1 with 1,500 specimens ha^{-1} fed granulated feed (Table 5).

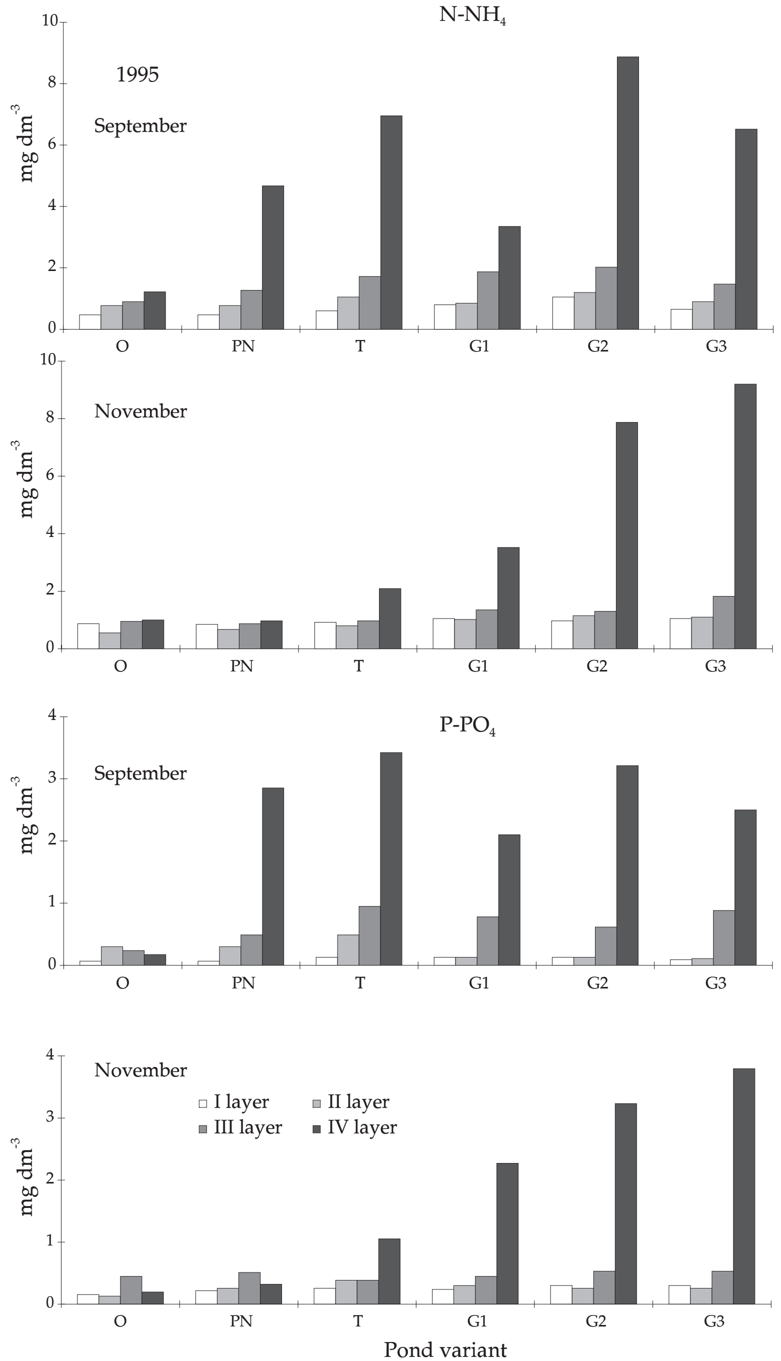

Fig. 3. Amounts of ammonia nitrogen and phosphates in the different water layers of the drained ponds.

TABLE 5

Magnitude of organic matter, nutrient and suspended matter load and indicators of the balance of chemical oxygen demand COD_{Mn} in 1995

	COD_{Mn}	difference (outflow-inflow)	$N_{NO2}+N_{NO3}+N_{NH4}$	difference (outflow-inflow)	P-PO_4	difference (outflow-inflow)	Suspended matter
Inflow	61.5		30.0		4.1		
			September				
Outflow							
O	175.5	114.0	10.5	-19.5	1.8	-2.3	975
PN	230.0	168.5	16.5	-13.5	5.1	1.0	880
T	249.5	188.0	28.5	-1.5	7.5	3.4	886
G1	145.5	84.0	20.5	-9.5	4.8	0.7	828
G2	189.5	128.0	31.0	1.0	5.5	1.4	689
G3	172.0	110.5	23.5	-6.5	5.5	1.2	699
			November				
Outflow							
O	78.5	17.0	12.0	-18.0	2.2	-1.9	537
PN	70.7	9.2	12.5	-17.5	3.0	-1.1	452
T	78.5	17.0	14.0	-16.0	4.0	-0.1	479
G1	91.0	29.5	18.7	-11.3	5.1	1.0	422
G2	130.5	69.0	23.0	-7.0	6.4	2.3	543
G3	116.0	54.5	26.0	-4.0	6.9	2.8	379

The highest COD_{Mn} occurred in ponds with 500 specimens ha^{-1} fed natural food (PN) and 1,500 specimens ha^{-1} (T) fed grain feed; they were similar in the other variants. The highest nitrogen load was reported in G2-type ponds (4,000 specimens ha^{-1}), while the highest phosphorus was noted in T-type ponds. The lowest loads were observed in ponds without fish (0). As the number of fish increased, the amount of suspension decreased to 975 kg ha^{-1} in 0-type ponds and to 700 kg ha^{-1} for G3-type ponds. These values were two times lower in November than they had been in September. The lowest suspended matter loads (700 kg ha^{-1}) were observed in G3-type ponds (4,000 specimens ha^{-1}); in the other variants, this figure was approximately 1,000 kg ha^{-1}.

The author used the results of her own research on the pond input water to estimate the organic matter and nutrients in it (Table 2b). It was determined that 61.5 kg O_2 ha^{-1} of organic matter (expressed as COD_{Mn}), 30 kg ha^{-1} of mineral nitrogen and 4.1 kg ha^{-1} of phosphates were introduced with the input water. The data indicate that in September in all pond variants mineral nitrogen was fully retained, phosphates were either partially or fully retained (in relation to the input water) and an especially high load of organic matter was observed, especially in ponds with 500 and 1,500 specimens ha^{-1}. In November these quantities were much lower since the confirmed excess (determined in relation to the input water in spring) of organic matter (expressed as chemical oxygen demand COD_{Mn}) in the water of G2- and G3-type ponds was two-fold higher than in September, and in the remaining pond types it was even more than ten-fold lower.

STUDY II – 1996

The amount of organic matter per ha of pond area increased with increasing stock density from 50 kg ha^{-1} in O-type ponds (no fish) to 200 kg ha^{-1} in G1 (1,500 specimens ha^{-1}) (Table 6).

TABLE 6

Magnitude of organic matter, nutrient and suspended matter and indicators of the balance of chemical oxygen demand COD_{Mn} in 1996

	COD_{Mn}	difference (outflow-inflow)	N_{NO2}+ N_{NO3}+N_{NH4}	difference (outflow-inflow)	P-PO_4	difference (outflow-inflow)	Suspended matter
Inflow	49.2		24.2		3.7		
			September				
Outflow							
O	49.6	0.4	8.0	-16.2	1.5	-2.2	828
PN	69.4	20.2	18.4	-5.8	4.7	1.0	1,078
T	162.2	113.0	34.3	10.1	10.3	6.6	1,213
G1	200.7	151.5	29.8	5.6	6.0	2.3	768
G2	157.7	108.5	41.8	17.6	10.1	6.4	641
G3	133.7	84.5	32.8	8.6	11.6	7.9	776
			November				
Outflow							
O	56.4	7.2	12.5	-11.7	1.2	-2.5	440
PN	58.6	9.4	22.3	-1.9	6.2	2.5	675
T	90.5	41.3	23.2	-1.0	5.5	1.8	551
G1	99.6	50.4	18.6	-5.6	7.4	3.7	478
G2	134.6	85.4	44.2	20.0	12.1	8.4	463
G3	136.5	87.3	26.2	2.0	7.0	3.3	433

In ponds with 1,500 and 4,000 specimens ha^{-1} (T, G1, G2, G3) the load of mineral nitrogen and phosphates was similar and remained at the highest level. The amounts of suspension in the majority of pond types (O, G1, G2, G3) were similar and lower than those in PN- and T-type ponds. In November the loads of organic matter and nutrients were comparable with those in September. However, the amounts of total matter were two times lower than in September. The highest permanganate value were observed in September in T- and G1-type ponds (1,500 specimens ha^{-1}), while in November the values were two times lower.

The results of chemical analyses of the water used to fill the ponds (Table 2b) and that discharged from the ponds (Table 6) were used to determine the balance of COD_{Mn} and the amount of nutrients in the studied ponds. The average values derived from the chemical analyses of several spring studies indicated that the water introduced to the ponds was characterized by an COD_{Mn} of 49.2 kg O_2 ha^{-1} and contained 24.2 kg ha^{-1} of mineral nitrogen (N-NO_2 + N-NO_3 + N-NH_4) and 3.7 kg ha^{-1} of phosphates. The data indicate that only in November was mineral nitrogen fully retained in the ponds with carp stock densities of 0, 500 and 1,500 per ha. The impact of the level of production intensity on the COD_{Mn} of water was also observed in November; it increased in comparison with the supply water as the stock density increased.

STUDY III – 1997

The highest values of COD_{Mn}, suspended matter, mineral nitrogen and phosphates were reported in September in G3-type ponds (Table 7).

During this period, the degree of fish production intensification had a significant impact on the suspension content, and it reached its maximum in the G3-type pond. The loads of organic matter, nutrients and suspended matter in the discharged water in November were smaller than in September, and especially high decreases were observed in ponds with the largest stock densities (4,000 specimens ha^{-1}).

Table 2b presents the average values of the results of analyses conducted in three spring periods. These data indicate that significant amounts of organic matter expressed as COD_{Mn} of 61.2 kg O_2 ha^{-1}, 12.3 kg ha^{-1} nitrogen (N-NO_3 + N-NH_4) and 1.5 kg P-PO_4 ha^{-1} reached the ponds at these times. These results indicate that the waters discharged during the September harvest into the recipient basins carried significant amounts of organic matter, nitrogen and phosphorus. The highest levels of these substances were in waters from G3-type ponds. The retention of mineral nitrogen and phosphates was observed only in waters discharged from ponds either with no fish or with the lowest stock density. The figures for the waters discharged from the ponds in November were much better. Full nutrient retention and partial organic matter retention were recorded in

TABLE 7

Magnitude of organic matter, nutrient and suspended matter load and indicators of the balance of chemical oxygen demand COD_{Mn} in 1997

	COD_{Mn}	difference (outflow-inflow)	N_{NO2}+ N_{NO3}+N_{NH4}	difference (outflow-inflow)	P-PO_4	difference (outflow-inflow)	Suspended matter
Inflow	61.2		12.3		1.5		
			September				
Outflow							
O	117	55.5	9.0	-3.3	1.0	-0.5	364
PN	99.7	38.5	10.4	-1.9	2.0	0.5	650
T	118.4	57.2	23.8	11.5	7.5	6.0	601
G1	104.5	43.3	13.8	1.5	2.8	1.3	812
G2	154.9	93.7	25.6	13.3	6.8	5.3	1,181
G3	248.9	187.7	27.5	15.2	8.1	6.6	1,456
G4	119.8	58.6	21.9	9.6	4.8	3.3	1,056
			November				
Outflow							
O	61.9	0.7	6.9	-5.4	1.2	-0.3	772
PN	66.9	5.7	6.4	-5.9	1.0	-0.5	412
T	62.9	1.7	8.5	-3.8	1.2	-0.3	506
G1	70.5	9.3	12.3	0	1.5	0	270
G2	92.6	31.4	9.9	-2.4	2.8	1.3	506
G3	79.4	18.2	11.9	-0.4	1.8	0.3	626
G4	65.8	4.6	7.6	-4.7	1.7	0.2	874

all study variants. This beneficial situation was observed in the G3-type pond; the waters discharged from it in November carried organic matter levels which were ten-fold lower than those from ponds with the same stock density in September.

DISCUSSION

Hydrobiologists and ecologists have been discussing the impact of intensive fish production on the purity of surface waters since the early 1990s (Kosturkiewicz et al. 1993, Szumiec and Kolasa-Jamińska 1997). This method of fish production raises certain concerns since allochtonic substances such as feed (Piotrowska-Opuszyńska1984) and fertilizers (Lewkowicz and Lewkowicz 1976) are released into the ponds during the production season. Autochthonous substances appear in the ponds during the vegetation season and these might also be a cause of surface water pollution (Kolasa-Jamińska 1994, 1996). The large amounts of feed used in intensive production, which can be improperly balanced or of improper nutritional value, can also have an adverse impact on the pond environment (Prikryl et al. 1983). According to some researchers (Seyour and Bergheim 1991), the use of feed itself poses the greatest threat to water purity. The fish used in the studies presented in this paper were fed with precisely prescribed dosages of granulated feed containing 32% protein, which falls within the optimum amount for carp feed (Wilson 1991).

One of the most important factors which protects the biocenosis of reservoirs is the appropriate level of dissolved oxygen in the discharged water (Danielewski 1970). The water discharged from ponds had a saturated oxygen content of 70%, and only in a few cases were the levels lower than the accepted minimum (EIFAC 1974). The water pH, which varied from 7.0 to 8.5, was safe for the aquatic environment and its organisms (Jezierska 1988).

The amounts of nutrients and organic matter which increased as the successive layers of water were drained from the pools did not pose any threat for the recipient basins (Jezierska-Madziar1986, Marek et al. 1997). As expected, the draining of the fourth layer posed a threat (Krüger and Piotrowska 1974, Jezierska-Madziar 1995). In the current study, this was especially apparent in the ponds with high stock densities (G2 and G3) and in which the final fisheries production was the highest. Water drained from layer IV contained large amounts of suspensions, ammonia nitrogen, phosphates and organic matter (expressed as COD_{Mn}). These substances cause eutrophication, oxygen deficits and bottom silt build-up in the recipient basins.

The magnitudes and types of pollution loads discharged from pond complexes are especially important with regards to aquatic environmental protection. The results obtained by Krüger and Piotrowska (1974) indicate that waters discharged from the ponds may be comparable to flood waters which are loaded with significant levels of suspensions. In this study, organic matter and suspensions were the key components of the discharged pollution, while nutrient amounts were very low. An average of 1,000 kg of suspended matter, organic matter and nutrients were discharged from one hectare of carp pond area. Although this amount of pollution does not pose a threat to the quality of flowing waters (Backiel 1979), it may pose a problem for lake waters (Mańczak 1979, Jezierska-Madziar 1986).

The large differences in stock densities produced only small differences in the levels of the studied nutrients per hectare of pond area. The similar nutrient levels in the post-production waters of ponds exploited at various production intensity means that, when recalculated into the mass of fish produced, relatively smaller pollution loads will be discharged from ponds operating at higher production intensities. Significant increases in stock density, for example from 500 to 4,000 specimens ha^{-1}, did not result in a proportional increase of total pollution. The amounts of pollution per hectare of pond area were, in the majority of cases, similar. The exception was in 1997, when they were two-fold higher.

The pollution load in the discharged post-production waters of each pond complex differ and depend on the purity of the input water, the fish production methods and the quality and quantity of the feed used. The ponds in the Gołysz complex are supplied with Vistula River water. An increase in the nutrient levels in the waters of the Upper Vistula River drainage area have recently been observed. Studies conducted in recent years in the area of the Vistula source have indicated there are increased amounts of ammonia nitrogen and nitrate nitrogen in the water (Wróbel 1995). The author's own 20-year-long research of the supply waters reveals that ammonia nitrogen content has increased from 0.45 to 0.65 mg $N\text{-}NH_4$ dm^{-3} and that phosphates have more than tripled from 0.097 to 0.367 mg $P\text{-}PO_4$ dm^{-3} (Kolasa-Jamińska, unpublished data). During the current three-year-long study, the amounts of ammonia nitrogen and organic matter in the water flowing into the ponds fell within the first class of surface water purity and those of phosphates in the first (1997) or second (1995 and 1996) class.

During the spring, the ponds can play a positive role as water is drained off of rivers with high water levels thus reducing the danger of flooding (Drabiński et al. 1994). The carp ponds do not pose a threat to the natural environment in summer, and they have a positive impact on the microclimate and the ground water levels in their vicinity (Karpiński 1995). Only in fall, when post-production waters are discharged, do the ponds pose the greatest threat to the ecosystems of the recipient basins (Krüger and Niewiadomska-Krüger 1989). This is mainly true for ponds with intensive fish production, since both low and high intensity production improves the purity of the drained waters (Kosturkiewicz et al. 1993, Tucholski and Niewolak 1994). A comparison of the amount of organic matter and nutrients in the waters of the Vistula River with those discharged from ponds in September indicated that the latter had higher levels of organic matter and either smaller or only slightly excessive amounts of ammonia nitrogen and phosphates. Knösche et al. (1998) also noted significant nutrient retention in the ponds. More advantageous parameter levels were recorded during the November harvest. Although the excess of organic matter was lower than it had been in September, there was full nitrogen retention and only a slight excess of phosphates. It was confirmed that a 40-day shift in harvest resulted in lower levels of mineral nitrogen in the discharged water than those in the Vistula River.

The progressive eutrophication of surface waters in recent years is caused mainly by the rapid increase of phosphorus levels in the water (Mańczak 1979, Solski 1992, Januszkiewicz 1995). According to Stumm and Stumm-Zollinger (1972), 1.0 mg $P\text{-}PO_4$ is more dangerous to lakes than 50-100 mg of organic matter. Controlling excessive eutrophication cannot be achieved by discontinuing the use of fisheries ponds, which are an important element in the regulation of processes in their ecosystems (Piotrowska-Opuszyńska 1989), as this would lead to overgrowth by emerged flora, the ponds becoming shallower and then their disappearance (Pokorny et al. 1992). The results of the current studies indicate that in comparison with input water the post-production waters discharged from the ponds most frequently exhibit either full retention or a minimum excess of phosphates. This has an impact on the quality of waters in the recipient basins (the Vistula River, Goczałkowicki Reservoir). At the same time, the seven-kilometer-long, meandering drainage canal which transports waters to the Goczałkowice Reservoir may have a positive impact on distribution and contribute to a decrease in suspension or organic matter levels. It is essential to point out that the partial retention of pollution loads was observed in ponds with high fish production intensity, i.e. G2 and G3 (4,000 specimens ha^{-1}); however, at a level of low intensity (1,500 specimens ha^{-1}), which is applied in 98% of Polish carp ponds, this is not a threat.

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STRESZCZENIE

INTENSYFIKACJA CHOWU RYB A WIELKOŚĆ ŁADUNKU ZANIECZYSZCZEŃ ODPROWADZANEGO W CZASIE JESIENNEGO ODŁOWU STAWÓW

Chów karpia prowadzono w polikulturze z amurem białym, tołpygą białą i sumem europejskim w stawach o jednakowej powierzchni 0,15 ha i jednakowej głębokości 1,5 m (tab. 1). Celem badań było określenie zmian zachodzących wraz ze spuszczaniem wody z czterech warstw (rys. 1) w stawach obsadzonych różną ilością karpia, obliczenie wielkości ładunków zanieczyszczeń i określenie retencji biogenów i materii organicznej. Badania dotyczyły odczynu wody, zawartości tlenu, zawiesiny ogólnej, utlenialności nadmanganianowej w środowisku kwaśnym, form azotu (azotynowego, azotanowego, amonowego i ogólnego) i fosforanów. W miarę spuszczania wody ze stawów wzrastała ilość azotu amonowego, fosforanów (rys. 3), zawiesiny ogólnej i utlenialności nadmanganianowej. Najwyższe wartości, szczególnie zawiesiny ogólnej i utlenialności, notowano w ostatniej fazie spuszczania stawów czyli w czwartej warstwie zalewowej (rys. 2). Potwierdzeniem tego był test NIR przeprowadzony dla powyższych parametrów chemicznych (tab. 4).

Obliczono wielkości ładunków materii organicznej, zawiesiny ogólnej i biogenów. Obciążenie wody spuszczanej ze stawów materią organiczną (wyrażaną utlenialnością nadmanganianową w środowisku kwaśnym), azotem, fosforem i zawiesiną określono na jednostkę powierzchni (1 ha). Najwyższe wartości badanych parametrów chemicznych notowano dla stawów wariantu T (1500 szt. ha^{-1}), G2 i G3 (4000 szt. ha^{-1}).

W każdym kompleksie hodowlanym obciążenie wód odprowadzanych do odbieralników ładunkiem zanieczyszczeń będzie inne, zależne od czystości wody wykorzystywanej do napełnienia stawów wiosną (tab. 2a, b), gatunków ryb i metod ich chowu w czasie sezonu wegetacyjnego (tab. 3a, b, c). Porównano wartości parametrów chemicznych (w kg ha^{-1}) wód spuszczanych ze stawów jesienią z poziomem utlenialności i ilością biogenów wprowadzanych do stawów wiosną i określono w jakim stopniu następowała w stawach retencja biogenów i materii organicznej (tab. 5, 6, 7). Z porównania wynika, że w większości przypadków występowała pełna retencja azotu mineralnego, retencja lub minimalny nadmiar fosforanów oraz wyższa, zwłaszcza przy odłowach we wrześniu, wartość utlenialności wody.

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