Evaluation of the poly- and monoculture production of the common carp *Cyprinus carpio* L. and the sharptooth catfish *Clarias gariepinus* (Burchell) in final effluent oxidation pond water of a sewage purification system

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Abstract

The two fish species *Clarias gariepinus* and *Cyprinus carpio* were produced in poly- and monoculture in final effluent sewage maturation pond water. Yields of more than 6 t of fish·ha^{-1} were obtained in polyculture within a 100-d production period using overwintered juvenile stock. Late summer production under monoculture conditions for each species was, however, less favourable partly due to the water temperatures which dropped to below 20°C and the use of juvenile fish bred during the same season. The investigation showed that sewage effluent water can be used to obtain good fish yields using the two species *C. gariepinus* and *C. carpio* in polyculture.

Introduction

Periodic shortages of water for use in aquaculture in large parts of Southern Africa necessitate investigations into the utilisation of water such as treated effluent water from sewage works, which is otherwise unsuitable for domestic purposes, in these regions. These waters, which are rich in nutrients, are usually discharged into streams without any further use. The effluent water from most well-designed maturation pond systems in South Africa is, in general, of such good quality that many fish species, including the sharptooth catfish and the common carp, usually survive in ponds receiving the final effluent water from these systems. At least one such system near Kimberley in the Cape is known to be utilised successfully for the commercial production of the sharptooth catfish *Clarias gariepinus*.

Published records on the use of effluent water from domestic sewage in fish production, date back to the early part of this century. In South Africa, Hey (1955) reported on the use of sewage effluent water in fish production. Published records on the practical commercial application of animal manures and treated sewage effluent, began to appear during the 1960s (Hepher and Schroeder, 1975). Mortimer et al. (1963) and Woynarovich (1976) discuss in detail how animal husbandry, such as pig and poultry farming, can be combined with fish production. The fish production potential of organic fertiliser in fish ponds is discussed by Schroeder (1974), Schroeder and Hepher (1976), and Moav et al. (1977). Schroeder (1974) and Hepher and Schroeder (1975), recorded fish yields of as much as 20 to 40 kg·ha^{-1}·d^{-1} by using cattle manure and treated sewage effluent respectively as organic nutrients without the use of supplementary feeds. There is, therefore, no doubt that the potential productivity of nutrient-rich sewage effluent water can in fact replace a portion of the feeds required mainly in the form of naturally produced proteins. The necessity of using a high protein formulated feed, normally required in high density production of fish species such as the sharptooth catfish, is thus reduced (Hecht et al., 1988).

The present series of investigations were aimed at assessing the fish production potential of water from sewage maturation pond systems in a temperate region of South Africa (Pietersburg, Transvaal) which lies at an altitutde of 1 220 m above sea level and where prevailing mean water temperatures of above 20°C occur only between mid-October (spring) and mid-April (autumn). The two fish species investigated in poly- and monoculture in the final effluent water of the Seshego water purification works, were the European common carp *Cyprinus carpio* and the sharptooth catfish *Clarias gariepinus*.

Materials and methods

Fish ponds used and stocking densities

Two ponds of approximately 1 ha in size each, supplied with a constant flow of final effluent water of approximately 2 to 3 cusecs from the maturation pond system were used for the investigation. Two separate trials were performed, one in polyculture where both species were stocked together in approximately equal numbers and at a total stocking density of 11 045 fish·ha^{-1}, and another in monoculture where the fish were stocked separately in the two ponds at stocking densities of 10 000 fish·ha^{-1} each (Tables 1 and 2). The polyculture investigation was carried out during the early summer season of 1987, between the end of September (spring) and the middle of December (mid-summer). The second monoculture investigation with *C. carpio* and *C. gariepinus* commenced immediately after the polyculture study in January 1988 and lasted for 126 d until 6 June when the mean pond water temperature declined to 16°C.

All fish used during the first polyculture part of the investigation, were from overwintered stock kept in rearing ponds at the site of the project. At the time of stocking, the individual mean mass of the common carp and sharptooth catfish was 124,0 g and 166,4 g respectively. In the second part of the experiment, fish of both species used were from material reared during the spring of the same summer growing season. Because of this, the mean individual mass of the fish at the onset of the monoculture experiments was only 26,2 g and 27,2 g for the common carp and sharptooth catfish respectively.

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TABLE 1
MEAN VALUES FOR PHYSICAL AND CHEMICAL CONDITIONS IN THE TWO POLYCULTURE PONDS MONITORED WEEKLY FOR 7 SUCCESSIVE FORTHNIGHTLY PERIODS COMMENCING 5 OCTOBER 1987, ENDING 30 DECEMBER 1987. FOUR SETS OF ANALYSIS WERE CONDUCTED PER PERIOD (n=8)

Chemical parameters	Period in fortnights						
	1	2	3	4	5	6	7
Dissolved oxygen ($mg \cdot \ell^{-1}$)	10,2	8,75	6,77	6,07	7,57	7,67	8,53
pH	7,76	9,59	8,53	7,96	8,75	9,20	9,38
Conductivity ($\mu S \cdot cm^{-1}$)	805	803	226	845	882	857	773
Nitrate (NO_3) ($mg \cdot \ell^{-1}$)	-	-	70,9	53,1	47,9	33,9	28,5
Nitrite (NO_2) ($mg \cdot \ell^{-1}$)	-	-	3,06	3,28	3,25	2,00	1,65
Ammonia (NH_4) ($mg \cdot \ell^{-1}$)	-	-	0,42	0,92	0,41	0,54	0,67
Orthophosphate (PO_4) ($mg \cdot \ell^{-1}$)	-	-	3,81	6,41	6,56	4,98	3,17
Alkalinity as $CaCO_3$ ($mg \cdot \ell^{-1}$)	-	-	115,5	162,5	175,7	179,2	166,5
Ca hardness as $CaCO_3$ ($mg \cdot \ell^{-1}$)	-	-	65,0	66,7	64,0	58,2	56,0
Total hardness as $CaCO_3$ ($mg \cdot \ell^{-1}$)	-	-	104,2	137,2	149,0	139,0	124,5

TABLE 2
MEAN VALUES FOR PHYSICAL AND CHEMICAL CONDITIONS IN THE 2 MONOCULTURE PONDS FOR *C. CARPIO* AND *C. GARIEPINUS* RESPECTIVELY (n=2 PER PERIOD PER POND). INVESTIGATIONS COMMENCED 1 FEBRUARY 1988, AND ENDED 6 JUNE 1988

Chemical parameters	Ponds	Period in fortnights							
		1	2	3	4	5	6	7	8
Dissolved oxygen ($mg \cdot \ell^{-1}$)	*C. carpio*	10,2	6,8	11,7	11,9	8,1	11,9	13,2	9,3
	C. gariepinus	3,7	7,8	7,2	5,9	6,7	10,1	7,6	5,3
pH	*C. carpio*	10,52	9,36	9,97	9,81	9,64	9,56	9,08	8,41
	C. gariepinus	9,67	9,89	9,57	9,18	9,15	8,98	8,78	8,10
Conductivity ($\mu S.cm^{-1}$)	*C. carpio*	825	772	796	693	668	688	770	859
	C. gariepinus	746	728	724	705	690	685	747	846
Nitrate (NO_3) ($mg \cdot \ell^{-1}$)	*C. carpio*	1,48	2,67	0,79	1,07	2,14	1,96	1,82	1,65
	C. gariepinus	2,61	3,17	1,62	1,68	1,11	0,51	1,55	1,52
Nitrite (NO_2) ($mg \cdot \ell^{-1}$)	*C. carpio*	26,40	41,80	57,64	46,64	40,04	37,40	66,00	78,70
	C. gariepinus	15,84	19,80	16,28	23,32	18,92	7,48	47,96	73,40
Ammonia (NH_4) ($mg \cdot \ell^{-1}$)	*C. carpio*	0,79	0,33	0,49	0,26	0,37	0,41	0,32	0,85
	C. gariepinus	1,16	0,33	0,44	0,30	0,55	0,56	0,49	0,11
Orthophosphate (PO_4) ($mg \cdot \ell^{-1}$)	*C. carpio*	1,33	2,86	4,61	2,95	2,88	4,84	6,30	6,92
	C. gariepinus	1,35	2,17	2,25	2,89	2,75	3,09	5,31	6,63
Alkalinity as $CaCO_3$ ($mg \cdot \ell^{-1}$)	*C. carpio*	120	121	123	138	120	135	155	173
	C. gariepinus	160	149	143	139	143	158	164	174
Ca hardness as $CaCO_3$ ($mg \cdot \ell^{-1}$)	*C. carpio*	47	47	50	52	47	57	81	104
	C. gariepinus	57	49	50	47	49	52	70	120
Total hardness as $CaCO_3$ ($mg \cdot \ell^{-1}$)	*C. carpio*	67	82	94	103	99	112	167	188
	C. gariepinus	101	93	85	89	98	106	152	189

TABLE 3
STOCKING AND FINAL DENSITIES AND PRODUCTION RESULTS OF THE POLYCULTURE PRODUCTION OF THE COMMON CARP *CYPRINUS CARPIO* AND THE SHARPTOOTH CATFISH *CLARIAS GARIEPINUS* IN PONDS RECEIVING FINAL EFFLUENT WATER FROM MATURATION PONDS AT THE SESHEGO SEWAGE PURIFICATION WORKS

Period	Days	Date	Mean and extreme temperatures (°C)	Estimated numbers of fish	Stocking(s) and final (f) densities (fish·ha^{-1})	Estimated mass of fish in ponds (kg)	Harvested fish mass (kg)	Estimated (E) and final (F) standing crop (kg·ha^{-1})	Yield in kg·ha^{-1}	Production in kg·ha^{-1}	Formulated feed dosage quantities in kg·ha^{-1}	Feed conversion ratio (FCR)
0	0	29/9			11 045(s)			1 601,3				
1	14	29/9-12/10	18,8 (23,0-13,5)		9 407			2 324,9(E)	723,6	51,7	480,4	0,66
2	28	13/10-26/10	20,1 (25,4-16,8)					2 866,6(E)	541,7	38,7	663,2	1,22
3	42	27/10-09/11	23,5 (28,0-19,8)					3 897,1(E)	1 030,5	73,6	1 573,2	1,52
4	56	10/11-23/11	22,9 (27,9-17,5)					4 831,8(E)	934,7	66,7	2 018,2	2,16*
5	70	24/11-07/12	25,1 (30,2-18,0)	9 228	179**	5 086,7	136,8	5 223,5(E)	391,4	27,9	1 143,5	2,92*
6	84	08/12-21/12	25,2 (28,5-22,2)	6 448	2 780**	4 086,8	1 936,8	6 022,9(E)	936,0	66,8	1 304,9	1,40
7	100	22/12-06/01	25,4 (30,3-20,3)		6 448**	-	4 078,2	6 151,5(F)	-	-	767,8	
TOTAL					9 507 (f)		6 151,5				7 951,2	$\bar{x}$=1,65

*Poor feed conversion due to nutritional problems with catfish
**Numbers of marketable fish cropped

Feed used

An 18% protein chicken broiler finisher pellet (Prinsloo and Schoonbee, 1987; Prinsloo et al., 1989) which was the least expensive animal feed available on the market during the present series of investigations, was used. Daily feed rations were applied at 2% of the total calculated biomass of fish during the first 28 d, when ample natural food is usually still available in the ponds (Cronjé, 1981). After 28 d, the daily feeding rates were adjusted to 4% of fish biomass·d^{-1}. This level was maintained for a further 72 d when all fish were of a marketable size. A similar feeding programme was followed during the monoculture experiment which, as mentioned, lasted for another 126 d. The fish were fed daily at 08:00, 10:00, 12:00 and 15:00. The staggering of the daily feeding programme avoided the problem of overfeeding encountered amongst the sharptooth catfish during a previous trial (Prinsloo et al., 1989).

A staggered harvesting programme was followed in the polyculture ponds as soon as some of the fish reached a marketable size. Harvesting commenced on day 70 and continued until the remainder of the fish were cropped at the end of the experiment. In the monoculture experiments, all fish were cropped on day 126 at the termination of the project.

Water chemistry of ponds

A Thies hydrothermograph was installed at a depth of 1 m in one pond, providing a continuous record of water temperature (°C). Water samples for chemical analysis were collected weekly from both ponds between 08:00 and 09:00.

The following water quality parameters were monitored according to Standard Methods (1980): Oxygen (mg·ℓ$^{-1}$), pH, conductivity (μS·cm^{-1}), ammonia (mg·ℓ$^{-1}$), nitrite (mg·ℓ$^{-1}$), nitrate (mg·ℓ$^{-1}$), phosphate (mg·ℓ$^{-1}$) alkalinity as $CaCO_3$ (mg·ℓ$^{-1}$), and total hardness as $CaCO_3$ (mg·ℓ$^{-1}$).

Results

Fourteen-day feeding periods were used before adjustments were made to the feeding rates of fish in the ponds. These adjustments were based on the mass increments of approximately 20% subsamples of fish taken from each pond. Measurements of the physical and chemical conditions in the ponds for each period are also listed accordingly in Tables 1 and 2.

Water chemistry

The results of the water quality analyses during both the polyculture and monoculture experiments, clearly reflect the high nutrient loads in the ponds. During the polyculture experiment (Table 1) mean values for dissolved oxygen remained high, fluctuating between a mean of 10,2 mg·ℓ$^{-1}$ (Period 1) and 6,07 mg·ℓ$^{-1}$ (Period 4). The water remained alkaline during the entire period of investigation with a maximum pH of 9,59 (Period 2). Conductivities were high, exceeding 800 μS·cm^{-1} during all but

TABLE 4
STOCKING AND FINAL DENSITIES AND PRODUCTION RESULTS OF THE MONOCULTURE PRODUCTION OF THE COMMON CARP *CYPRINUS CARPIO* IN PONDS RECEIVING FINAL EFFLUENT WATER FROM MATURATION PONDS AT THE SESHEGO SEWAGE PURIFICATION WORKS

Period	Days	Date	Mean and extreme temperatures (°C)	Stocking(s) and final (f) densities (fish·ha^{-1})	Mean individual mass of fish in g	Estimated (E) and final (F) standing crop (kg·ha^{-1})	Yields in kg·ha^{-1}	Production in kg·ha^{-1}·d^{-1}	Formulated feed dosage quantities in kg·ha^{-1}	Feed conversion ratio (FCR)
0	0	1/2	22,7	10 000(S)	26,19	261,9				
1	15	1/2-15/2	20,9-24,3	8 001,0	63,90	506,5(E)	244,6	16,3	133,9	0,5
2	28	16/2-28/2	22,4 21,1-23,6		105,98	847,9(E)	341,4	26,3	305,9	0,9
3	42	1/3-14/3	22,9 21,7-24,0		129,28	1 034,4(E)	186,5	13,3	519,1	2,8
4	56	15/3-28/3	24,3 22,5-26,2		216,25	1 730,2(E)	695,8	49,7	630,4	0,9
5	70	29/3-11/4	22,4 21,0-23,8		264,40	2 115,5(E)	385,3	27,5	1 038,2	2,7
6	83	12/4-24/4	20,1 18,5-21,7		318,68	2 549,7(E)	434,2	33,4	1 178,3	2,7
7	98	25/4-9/5	17,1 15,4-18,7		354,85	2 839,1(E)	289,4	19,3	1 660,1	5,7
8	126	10/5-6/6	16,3 14,7-18,0	8 001(f)	440,60	3 525,3(F)	686,1	24,5	2 768,6	4,0
Total							3 263,3		8 234,5	$\bar{x}$=2,5

the last period of investigation. The concentrations of nitrates were exceptionally high as could be expected from the type of water used, varying between 70,9 mg·ℓ^{-1} (Period 3) and 28,5 mg·ℓ^{-1}. Values for nitrite peaked during the earlier stages of the investigation when mean values exceeded 3 mg·ℓ^{-1} (Periods 3 to 5), but declined to a low mean of 1,65 mg·ℓ^{-1} during Period 7. Values for ammonia were moderate considering the type of water used, and fluctuated between 0,424 mg·ℓ^{-1} and 0,918 mg·ℓ^{-1}. Orthophosphates remained relatively high, varying between 3,17 mg·ℓ^{-1} (Period 7) and 6,54 mg·ℓ^{-1} (Period 5). Alkalinity concentrations were variable and comparatively high with values fluctuating between 115,5 mg·ℓ^{-1} (Period 3) and 179,2 mg·ℓ^{-1} (Period 6). This tendency is also reflected by the calcium and total hardness concentrations of the pond water as analysed during the various successive periods (Table 1).

The water chemistry of the fish ponds during the monoculture experiments (Table 2) basically reflected the same conditions as those experienced during the polyculture trials. Dissolved oxygen remained variable in both ponds with slightly higher means in the carp pond. High pH values were recorded (usually over 9), with values exceeding 10 during Period 1 in the carp pond. Conductivity fluctuated within the same range in both ponds, as was the case in the polyculture experiment. The concentrations of nitrate, nitrite and ammonia were similar to those recorded during the polyculture experiments. This also applies to concentrations of orthophosphate (compare Tables 1 and 2). Values for alkalinity, calcium and total hardness were generally of the same order as those obtained during the polyculture experiments.

Fish yields

Table 3 shows that the final fish yield after a production period of 100 d for the polyculture experiment, was 6 151,5 kg·ha^{-1}. Of this, carp contributed 3 606,5 kg·ha^{-1} (58,6% of total yield) and sharptooth catfish 2 545 kg·ha^{-1} or 41,4% of the total yield.

The mean individual mass of the carp and the sharptooth catfish at the end of the polyculture production period was 694,0 g and 603,7 g respectively. In both cases all fish were therefore of marketable size. Feed conversion ratios (FCR) calculated for the successive period showed extremely good conversation ratios during Periods 1 to 3 and 6 when values were generally below 1,5 (Table 3). The higher feed conversion ratio values recorded during Periods 4 and 5, were mainly due to problems associated with over-feeding. The mean FCR value for the entire period was 1,65. In the monoculture experiments (Tables 4 and 5), final yields

TABLE 5
STOCKING AND FINAL DENSITIES AND PRODUCTION RESULTS OF THE MONOCULTURE PRODUCTION OF THE SHARPTOOTH CATFISH *CLARIAS GARIEPINUS* IN PONDS RECEIVING FINAL EFFLUENT WATER FROM MATURATION PONDS AT THE SESHEGO SEWAGE PURIFICATION WORKS

Period	Days	Date	Mean and extreme temperatures (°C)	Stocking(s) and final (f) densities (fish·ha^{-1})	Mean individual mass of fish in g	Estimated (E) and final (F) standing crop (kg·ha^{-1})	Yields in kg·ha^{-1}	Production in kg·ha^{-1}·d^{-1}	Formulated feed dosage quantities in kg·ha^{-1}	Feed conversion ratio (FCR)
0	0	1/2		10 000(S)	27,16	271,6				
1	15	1/2-15/2	22,7 20,9-24,3	7 684	87,97	676,0(E)	404,4	27,0	145,1	0,3
2	28	16/2-28/2	22,4 21,1-1-23,6		127,19	977,3(E)	301,3	23,2	398,9	1,3
3	42	1/3-14/3	22,9 21,7-24,0		177,63	1 364,9(E)	387,6	27,7	602,6	1,6
4	56	15/3-28/3	24,3 22,5-26,2		260,81	2 004,1(E)	639,2	45,6	837,0	1,3
5	70	29/3-11/4	22,4 21,0-23,8		340,20	2 614,1(E)	610,0	43,6	1 249,9	2,0
6	83	12/4-24/4	20,1 18,5-21,7		381,50	2 931,4(E)	317,3	24,4	1 473,1	4,6
7	98	25/4-9/5	17,1 15,4-18,7		391,78	3 010,4(E)	79,0	5,3	1 982,8	25,1
8	126	10/5-6/6	16,3 14,7-18,0	7 684(f)	402,85	3 095,5(F)	85,1	3,0	2 499,8	29,4
Total							2 823,9		9 189,2	$\bar{x}$=8,2

for *C. carpio* and *C. gariepinus* were 3 263,3 and 2 823,9 kg·ha^{-1} respectively, over a production period of 126 d. Mean final individual mass at the end of the production period, was 440,6 g for carp and 402,8 g for catfish. In both cases all the fish were of marketable size.

The calculated FCR values for *C. carpio* were exceptionally good during Periods 1, 2 and 4 when values were below one. During the other periods, however, the FCR values exceeded 2,7 with a maximum estimated value of 5,7 at the end of the seventh period. The FCR values for *C. gariepinus* remained relatively favourable during the first 4 periods (Table 5) after which they increased to 2,0 in Period 5; 4,6 in Period 6 with extremely unfavourable FCR values during Periods 7 and 8. The dramatic increase in FCR values during the last 2 periods of the *C. gariepinus* monoculture production trial, coincided with mean water temperatures falling well below 20°C (Table 5). Although the feed dosage levels should have been reduced in the case of *C. gariepinus* during the later periods to coincide with a drop in pond water temperatures to below 20°C (Table 5) it was kept for the purpose of comparison at the same level as for *C. carpio,* which still actively fed at these temperatures.

Discussion

The present series of investigations confirmed, as recorded by other research workers, the value of maturation pond effluent water for warm-water fish production. Hepher and Pruginin (1981) state that domestic waste water in fish ponds, according to their experience, may be one of the best ways of manuring fish ponds and that waste water used in commercial fish production provided markedly higher fish yields than ponds which did not receive any. Demoll (1926) showed that diluted treated waste water yielded approximately 500 kg·ha^{-1} more fish than normal ponds. By using undiluted treated waste water only, Wolny (1962) obtained a fish yield of 1 318 kg·ha^{-1}. In Indonesia, Vaas (1948) obtained 3 t·ha^{-1} using the common carp, *C. carpio,* and *Punctius javanicus* in diluted domestic waste water. Similar fish tonnages were obtained by Jhingran (1974) in waste-water fish ponds in West Bengal, India using Indian carps in polyculture. Hepher and Schroeder (1977) showed that by adding treated domestic waste water to fish ponds, they could increase the yield of fish by 75% coupled with a marked improvement in the actual fish feed conversion ratio. Hepher and Pruginin's (1981) results clearly demonstrate the value of the increase in natural pond productivity in the total food availability in ponds when waste water is used. The present series of investigations also showed the significance of using overwintered juveniles when an early summer production of fish is considered. Fish of a marketable size were produced in November (early summer) allowing a possible second crop, should fish from the same overwintered stock be used. Fish bred during the early summer of the same year of production may, however, not all reach a marketable size as the production period could then extend into late autumn when mean pond water temperatures have already declined below 20°C affecting the growth and FCR of both fish species, in particular that of the sharptooth catfish. This tendency was clearly demonstrated by the present results (Tables 4 and 5) when a dramatic deterioration in the FCR values was recorded for *C. gariepinus*, the growth of which was much more susceptible to declining water temperatures, than that of *C. carpio*. With declining water temperatures, *C. carpio* maintained a much higher although not optimal growth rate, and thus provided better yields than *C. gariepinus* (Tables 4 and 5). On the basis of these results it is recommended that care should be taken not to extend the period of production of warm-water fish species, particular *C. gariepinus*, beyond March (autumn) in temperate regions of South Africa as a rapid deterioration in FCR can then be expected. The rate of feeding should also be adjusted downwards with declining water temperatures to coincide with the reduced feeding activities of the fish.

Another important factor which must be taken into consideration, is the protein content of the feed used. As increase in protein content might have had a favourable impact on the yields of both species. The cost of higher protein feeds may, however, have cancelled out the expected advantages of an improved yield under these specific circumstances.

The problem of faecal contamination of the fish grown in sewage effluent water is also an important factor which needs to be considered. Hepher and Pruginin (1981) state that fish may be potential carriers of bacterial and viral pathogens of human origin. There appears, however, to be controversy over whether enterobacteria would be able to multiply in the gut and tissues of fish which may render fish long-term vectors of human diseases, or whether fish may merely serve as passive carriers of these pathogens. They stress the importance of the natural capacity of fish ponds to purify waste water and thus reduce the number of pathogens present. Hepher and Pruginin (1981) concede that, should pathogens invade the flesh of fish, a prolonged period, probably months, could be required to depurate them. One way of ensuring that fish products from treated waste water will be free of pathogens, is to process the meat at high temperatures. During the present series of investigations none of the fish harvested were found to have any physical signs of disease. It is, however, advisable to conduct a specific investigation under local conditions into the problem of pathogens in fish ponds and to investigate the possibility that it may pose a health threat to consumers.

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VOLUME 17
1991

CONTENTS AND AUTHOR INDEX

Supplement to *Water SA* Vol. 18 No. 1

CONTENTS

VOL 17 • NO 1 • JANUARY 1991

VOL 17 • NO 2 • APRIL 1991

AUTHOR INDEX

Page numbers in **bold** refer to sole or first author: