The use of triploid grass carp, *Ctenopharyngodon idella* (Val.), in the control of submerged aquatic weeds in the Florida Lake, Roodepoort, Transvaal

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Abstract

Sterile triploid grass carp, *Ctenopharyngodon idella* (Val.) were introduced, at a stocking density of 35 fish·ha^{-1}, into the Florida Lake, Transvaal for the control of the submerged weeds *Potamogeton pectinatus* and *Lagarosiphon* spp. Within a period of one year the mean wet mass standing crop of both weeds in the lake declined from an initial 193,11 g·m^{-2} in March 1990 to 33,89 g·m^{-2} in January 1991. No major changes were encountered in the water chemistry of the lake. Reduction in weed growths coincided with changes in the populations of weed- and fish-eating birds frequenting the lake.

Introduction

The influx of people from the rural to the urban areas of South Africa was largely accelerated by the establishment of gold and coal mines in certain regions of the country. This was accompanied by the development of secondary industries, particularly those which were not only dependent on substantial quantities of water for the processing of their products, but also responsible for effluent discharges into streams, lakes and reservoirs, thereby causing a number of severe water quality problems (Harrison, 1958; Oliff, 1960; Allanson, 1961; Harrison, 1961; Schoonbee, 1963 a-c; Schoonbee and Kemp, 1963; Van der Merwe et al., 1990). Treated and untreated domestic sewage effluents from residential areas further contribute towards loads of pollutants which enter the catchment areas of the Vaal River and a number of other larger river systems in South Africa. Problems which have arisen from the various kinds of pollution include the mineralisation of systems, the eutrophication of such water bodies (Steÿn et al., 1975 a,b; 1976 a,b; Schoonbee et al., 1985) as well as the release of a variety of heavy metals which enter various food-chains in the affected aquatic ecosystems (Bezuidenhout et al., 1990; De Wet et al., 1990; Van der Merwe et al., 1990).

The eutrophication of lakes and reservoirs results in blooms of algae and excessive growths of aquatic weeds, which not only obstruct irrigation canals, but also pose a serious threat to the effective management of such waters, and in particular their recreational use in the densely populated areas of the Witwatersrand (Schoonbee et al., 1985). Problems were experienced with the development of floating aquatic weeds e.g. *Eichhornia crassipes* (Mart.) and *Salvinia molesta* D.S. Mitchell (Edwards and Musil, 1975; Musil, 1977; Scott et al., 1979; Vermeulen and Rankin, 1990). Steps were taken, with various degrees of success, to control these plants using chemical and biological control procedures (Neser and Annecke, 1973; Cilliers, 1987, 1990). More recently, the invasion of submerged aquatic weeds in streams and lakes severely affected the recreational use of these waters on the Witwatersrand (Schoonbee et al., 1985).

One such body of water is the Florida Lake in the municipal region of Roodepoort near Johannesburg, where for the past ten years the fennel-leaved pondweed *Potamogeton pectinatus* L. as well as 2 species of *Lagarosiphon* namely *L. muscoides* (Harv.) and *L. major* (Ridley) Moss ex Wager have infested the Lake to the extent of seriously endangering angling, boating and yachting on this Lake.

A number of possible ways of combating these weeds were considered. One alternative was the use of mechanical weedcutters and the removal of plant material from the lake. This method of control of *P. pectinatus* had already been attempted in Germiston lake on the East Rand, but with little success (Schoonbee et al., 1985).

The use of herbicides was not considered, even though this method of control was shown to be successful in the eradication of the floating weeds *Eichhornia crassipes* and *Salvinia molesta* in Southern Africa (Edwards and Musil, 1975; Scott et al., 1979; Vermeulen and Rankin, 1990). It is also known from the literature that the concentration levels of certain aquatic herbicides required for the effective control of submerged aquatic weeds can be harmful to other non-target aquatic plants, and may also threaten the equilibria of an entire ecosystem (Newman and Way, 1966; Newman, 1967; Way et al., 1971; Brooker and Edwards 1974, 1975; Newbold, 1975; Kawatsu, 1977; Rehwoldt et al., 1977; McCorcle et al., 1979; Tooby, 1981; Tanner et al., 1990). Since the Florida Lake is visited by large numbers of people, there was also the danger that the safety limits for certain herbicides in water, as specified by the Department of Health in South Africa, would be exceeded and might potentially threaten the health of people using the lake for recreational purposes.

The only other remaining alternative was the use of biological agents to combat the threat of excessive growths of *P. pectinatus* and *Lagarosiphon* spp. Apart from *Tilapia sparmanii*, which is largely an algae feeder, no other fish in the lake appears to be able to control these weeds effectively. The red-breasted tilapia *T. rendallii* is the only other fish known to utilise aquatic vegetation as its major source of food (Jubb, 1967; Potgieter, 1974; Bruton et al., 1982). This fish species was also used on an experimental basis to control *P. pectinatus* in the Germiston Lake (Schoonbee et al., 1985), but, being a warm-water fish, could not survive the winter temperatures on the Transvaal highveld which can decline to below 10°C. The only other fish known to be a voracious aquatic weed-eater is the Chinese grass carp *Ctenopharyngodon idella* (Val.). This fish was first imported into South Africa in 1974 (Pike, 1974). Methods to spawn this fish artificially on a large scale under local conditions were developed by Schoonbee et al. (1978) and Schoonbee and Prinsloo (1984). It was successfully used to control *P. pectinatus* in Germiston Lake (Schoonbee et al., 1985). In 1989, however, the Chief Directorate of Nature Conservation in the Transvaal decided not to allow the release of potentially fertile

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TABLE 1
PHYSICAL AND CHEMICAL ANALYSES OF THE WATER OF THE FLORIDA LAKE DURING BIMONTHLY SAMPLING PERIODS AT 8 RANDOMLY SELECTED LOCALITIES BETWEEN FEBRUARY 1990 AND DECEMBER 1991

Physical and chemical parameters	Mean, standard-deviation and range	Month of survey: February n = 8	April n = 8	June n = 8	August n = 8	October n = 8	December n = 8
Temperature	$\bar{x}$ ± SA	23,7 ± 2,1	20,1 ± 1,8	10,9 ± 0,4	15,3 ± 1,0	21,8 ± 2,2	23,2 ± 0,7
(as °C)	Min - Max	20,0 — 26,0	17,0 — 22,0	10,0 — 11,0	14,0 — 17,0	17,0 — 24,0	22,0 — 24,0
	Range	6,0	5,0	1,0	3,0	7,0	2,0
pH	Min - Max	7,8 — 9,9	7,3 — 8,0	7,5 — 8,2	7,9 — 9,8	7,0 — 8,8	8,5 — 9,8
	Range	2,1	0,7	0,7	1,9	1,8	1,3
Dissolved oxygen	$\bar{x}$ ± SA	6,3 ± 1,1	6,1 ± 0,7	8,3 ± 1,1	7,6 ± 0,7	7,3 ± 0,5	6,1 ± 0,6
(as $mg \cdot \ell^{-1}$)	Min - Max	5,0 — 7,9	5,3 — 7,6	6,8 — 10,3	6,7 — 8,4	6,8 — 8,1	5,3 — 7,0
	Range	2,9	2,3	3,5	1,7	1,3	1,7
Conductivity	$\bar{x}$ ± SA	105,0 ± 11,0	115,0 ± 16,0	118,8 ± 15,5	112,5 ± 20,6	110,0 ± 17,7	157,5 ± 11,7
(as $\mu S \cdot cm^{-1}$)	Min - Max	85,0 — 120,0	90,0 — 130,0	80,0 — 150,0	80,0 — 150,0	80,0 — 140,0	130,0 — 170,0
	Range	35,0	30,0	40,0	70,0	60,0	40,0
Alkalinity	$\bar{x}$ ± SA	55,0 ± 9,3	50,5 ± 7,8	55,5 ± 10,0	51,3 ± 12,5	58,8 ± 8,1	58,5 ± 8,0
(as $mg \cdot \ell^{-1}$ $CaCO_3$)	Min - Max	40,0 — 70,0	40,0 — 64,0	42,0 — 70,0	40,0 — 80,0	42,0 — 68,0	44,0 — 72,0
	Range	30,0	24,0	28,0	40,0	26,0	28,0
Total hardness	$\bar{x}$ ± SA	77,5 ± 36,2	60,0 ± 9,0	72,0 ± 18,0	68,0 ± 11,1	67,9 ± 9,4	66,8 ± 7,8
(as $mg \cdot \ell^{-1}$ $CaCO_3$)	Min - Max	30,0 — 120,0	50,0 — 70,0	60,0 — 110,0	60,0 — 80,0	59,0 — 84,0	58,0 — 83,0
	Range	90,0	20,0	50,0	20,0	25,0	25,0
Ammonia	$\bar{x}$ ± SA	0,037 ± 0,031	0,057 ± 0,118	0,657 ± 0,218	0,090 ± 0,244	0,209 ± 0,294	1,128 ± 0,975
(as $mg \cdot \ell^{-1}N$)	Min - Max	0,001 — 0,070	0,001 — 0,342	0,500 — 1,110	0,031 — 0,244	0,006 — 0,854	0,540 — 3,420
	Range	0,069	0,341	0,610	0,213	0,848	2,880
Nitrite	$\bar{x}$ ± SA	0,025 ± 0,032	0,024 ± 0,028	0,036 ± 0,011	0,029 ± 0,005	0,037 ± 0,016	0,048 ± 0,014
(as $mg \cdot \ell^{-1}$ NO_3^-)	Min - Max	0,001 — 0,098	0,088 — 0,002	0,020 — 0,053	0,017 — 0,033	0,017 — 0,056	0,030 — 0,070
	Range	0,097	0,086	0,033	0,016	0,039	0,040
Nitrate	$\bar{x}$ ± SA	7,7 ± 4,5	3,5 ± 1,4	4,8 ± 2,0	5,4 ± 7,0	3,0 ± 0,9	3,7 ± 1,2
(as $mg \cdot \ell^{-1}$ NO_2^-)	Min - Max	1,8 — 14,0	0,9 — 5,3	1,8 — 8,4	0,0 — 4,0	1,8 — 4,2	2,2 — 5,7
	Range	12,2	4,4	6,6	4,0	2,4	3,5
Orthophosphate	$\bar{x}$ ± SA	0,836 ± 0,555	0,480 ± 0,741	2,814 ± 0,026	2,925 ± 0,085	1,088 ± 1,078	0,043 ± 0,017
(as $mg \cdot \ell^{-1}$ PO_4^{3-})	Min - Max	0,140 — 1,400	0,090 — 2,300	2,800 — 2,860	2,800 — 3,000	0,200 — 2,800	0,020 — 0,070
	Range	1,260	2,210	0,060	0,200	2,600	0,050
Sulphate	$\bar{x}$ ± SA	4,7 ± 2,8	12,0 ± 4,1	10,5 ± 6,7	9,2 ± 5,0	9,6 ± 4,8	38,0 ± 15,2
(as $mg \cdot \ell^{-1}$ SO_4^{2-})	Min - Max	2,0 — 10,0	7,0 — 18,0	5,0 — 22,0	4,0 — 21,0	1,0 — 17,0	23,0 — 60,0
	Range	8,0	11,0	17,0	16,0	16,0	37,0
Turbidity	$\bar{x}$ ± SA	8,1 ± 7,8	7,9 ± 5,5	7,6 ± 3,1	5,8 ± 3,6	13,1 ± 6,6	6,4 ± 2,6
(as FTU-units)	Min - Max	2,0 — 18,0	3,0 — 20,0	8,0 — 12,0	2,0 — 10,0	5,0 — 22,0	3,0 — 10,0
	Range	16,0	17,0	4,0	8,0	17,0	7,0

grass carp into local waters for the control of water weeds any more, as it was feared that this fish, which is extremely fecund, might spawn naturally and invade vegetated areas including wetlands where a number of bird sanctuaries are located. Permission was obtained in 1989 for the importation of sterile, triploid grass carp from the USA specifically for the control of *P. pectinatus* and *Lagarosiphon* spp. in the Florida Lake.

The present paper deals with results obtained in the control of these weeds in the lake using sterile triploid grass carp.

Materials and methods

Parasite-free, sterile triploid juvenile grass carp were imported from Lonoke, Arkansas in November 1989. On arrival, the fish, which had a mean individual mass of less than 2 g, were first acclimated in holding-tanks of the Department of Zoology at the Rand Afrikaans University in Johannesburg for a period of 2 weeks before they were transferred to grow-out ponds of the Provincial Fisheries Research Station at the Hartbeespoort Dam near Pretoria.

While the fish were being kept at the laboratory of the Rand Afrikaans University, they were provided with fresh *P. pectinatus* as well as a prophylactic treatment with pelleted formulated feed which contained Lintex, a cestocide used to eradicate the fish tapeworm *Bothriocephalus acheilognathi* (Brandt et al., 1981), which commonly occurs in the grass carp. This treatment was continued at the Hartbeespoort Dam grow-out ponds until the fish were ready for transfer to the Florida Lake.

The mean individual mass of the fish at the time of stocking was 89 g. They were transported in oxygen-filled plastic bags on 14 February 1990 and released into the lake at a stocking density of 35 fish·ha^{-1}.

An enlarged modified Forsberg sampler (Forsberg, 1959) was used for the quantitative evaluation of the standing crop of the submerged weeds in the lake.

A total of 20 randomly selected sampling sites were located in the lake where bimonthly samplings were conducted from the first week in March, 2 weeks after the release of the grass carp into the lake. In this way successive standing crop values could be compiled for both *P. pectinatus* and *Lagarosiphon* spp. during the sampling periods. In the laboratory the collected samples were individually weighed for wet mass determinations and oven dried at 90°C for approximately 36 h to obtain dry mass determinations. Results are expressed in tons of plant material per 26 ha (Table 2) (the size of the Lake) as well as in g·m^{-2} (Table 3) lake bottom. The total standing crop values for the 2 species of *Lagarosiphon* were grouped together.

Maps were compiled to show the decline and/or increase in standing crop of the submerged weeds over a period of one year (Fig. 1).

Collection of water samples for the physical and chemical analyses were done bimonthly between 9:00 and 12:00 according to Standard Methods (1971). Parameters analysed for were: temperature, pH, dissolved oxygen, conductivity, alkalinity, total hardness, ammonia, nitrite, nitrate, orthophosphate, sulphate and turbidity (Table 1).

TABLE 2
STANDING CROP IN m·t OF *POTAMOGETON PECTINATUS* AND *LAGAROSIPHON* SPP. IN THE FLORIDA LAKE (26,56 ha) IMMEDIATELY AFTER THE RELEASE OF THE GRASS CARP (MARCH 1990) AND DURING SUCCESSIVE BIMONTHLY INTERVALS

Month of survey	Standing crop in m·t					
	Wet mass			Dry mass		
	P. pectinatus m·t (%)	*Lagarosiphon* spp. m·t (%)	Total m·t (%)	*P. pectinatus* m·t (%)	*Lagarosiphon* spp. m·t (%)	Total m·t (%)
March	31,18 (100,0)	20,11 (100,0)	51,29 (100,0)	3,71 (100,0)	1,76 (100,0)	5,47 (100,0)
May	7,79 (25,0)	11,84 (58,9)	19,63 (38,3)	0,71 (19,1)	0,99 (56,3)	1,70 (31,0)
July	0,69 (2,2)	0,64 (3,2)	1,33 (2,6)	0,07 (1,9)	0,12 (6,8)	0,19 (3,5)
September	1,50 (4,9)	0,37 (1,8)	1,87 (3,7)	0,32 (8,6)	0,05 (2,8)	0,37 (6,8)
November	1,99 (6,4)	0,36 (1,8)	2,35 (4,6)	0,36 (9,8)	0,04 (2,3)	0,40 (7,3)
January	8,00 (25,7)	1,00 (5,0)	9,00 (17,5)	0,85 (23,0)	0,08 (4,6)	0,93 (17,0)

TABLE 3
DENSITIES OF *POTAMOGETON PECTINATUS* AND *LAGAROSIPHON* SPP IN THE FLORIDA LAKE EXPRESSED AS WET AND DRY MASS (g·m^{-2}) SUBSTRATE DURING SUCCESSIVE BIMONTHLY PERIODS FOLLOWING THE RELEASE OF THE GRASS CARP IN FLORIDA LAKE IN 1990

Month of survey	Plant density in g·m^{-2}					
	Wet mass			Dry mass		
	P. pectinatus	*Lagarosiphon* spp.	Total	*P. pectinatus*	*Lagarosiphon* spp.	Total
March	117,39	75,72	193,11	13,97	6,63	20,59
May	29,33	44,58	73,91	2,67	3,73	6,40
July	2,60	2,41	5,01	0,26	0,45	0,72
September	5,65	1,39	7,04	1,20	0,19	1,39
November	7,49	1,36	8,85	1,36	0,15	1,51
January	30,12	3,77	33,89	3,20	0,30	3,50

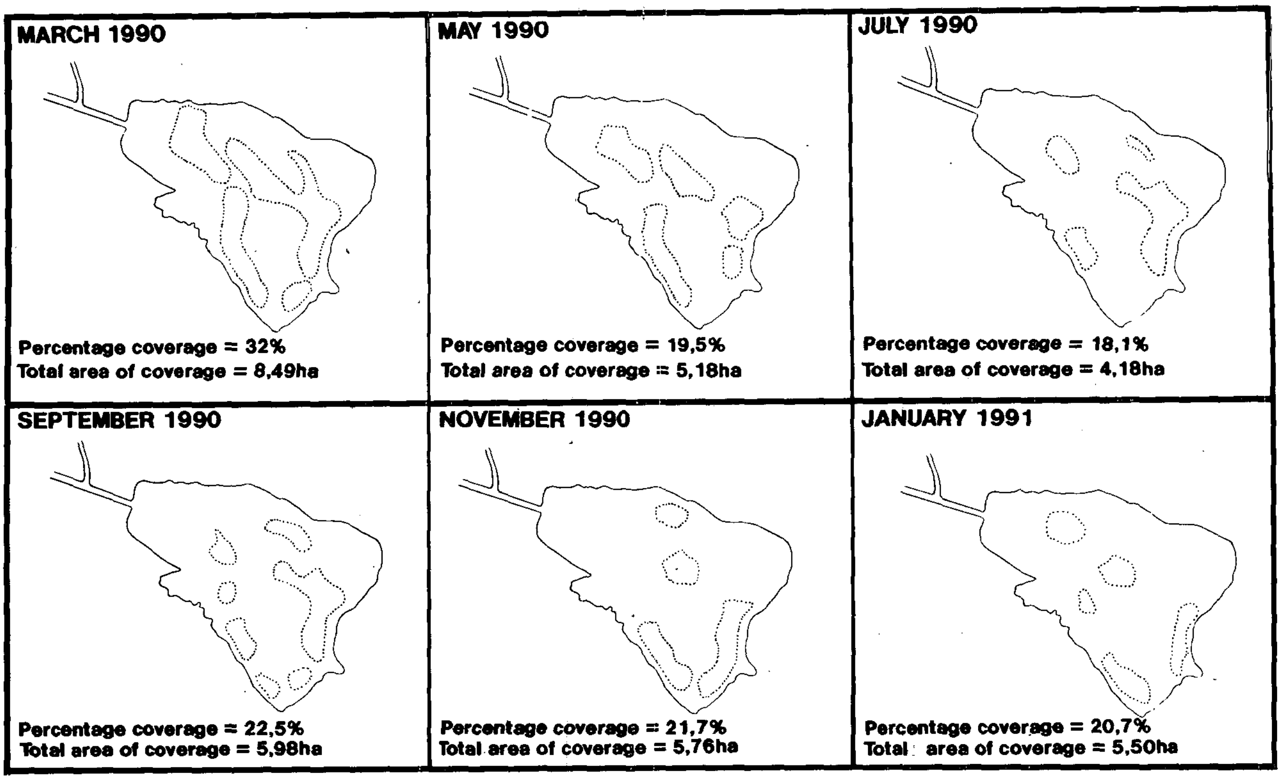

Figure 1

Distribution and area covered expressed as percentage of total lake area as well as surface area in ha of the submerged weeds Potamogeton pectinatus *a*
Lagarosiphon *spp. between the successive bimonthly sampling periods March 1990 and January 1991 in the Florida Lake, Roodepoort, Transvaal*

Results

Results on the selected physical and chemical parameters for which analyses were carried out, are summarised in Table 1. Mean water temperature ranged between a maximum of 23,7°C in summer (February 1990) to a winter low of 10,9°C (June 1990). Recorded pH values were fairly high on occasions, fluctuating between 7,0 (October 1990) and 9,9 (February 1991).

As all measurements were made between 9:00 and 12:00, values for dissolved oxygen were usually high, ranging between 6,1 mg·ℓ$^{-1}$ in summer and 8,3 mg·ℓ$^{-1}$ in winter. Depending on wet and dry spells, the dissolved salts as reflected by dionic conductivity were reasonably constant above 100 μS·cm^{-1}.

Values obtained for alkalinity and total hardness reflected moderately alkaline values. Concentrations of ammonia were fairly low, ranging between 0,037 mg·ℓ$^{-1}$ (February 1990) and 0,657 mg·ℓ$^{-1}$ (June 1990) with an unexpectedly high mean concentration of 1,128 mg·ℓ$^{-1}$ in December 1990. This coincided with peak values obtained for conductivity (157,5 μS·cm^{-1}) suggesting the influx of polluted waters into the lake, possibly as a result of rainfall.

Results recorded for nitrate were generally high (Table 1) and, together with the occasionally high values for orthophosphates, might explain the excessive growths of submerged weeds and algae in the lake. Peak values for sulphates were recorded during the summer when the highest values for parameters such as conductivity, ammonia and nitrites were also obtained. High turbidity readings of 13,1 FTU-units were recorded during the spring rainy season.

The changes in standing crop for the successive sampling periods between March 1990 and January 1991 of both *P. pectinatus* and *Lagarosiphon* spp., expressed in wet and dry mass, are listed in Tables 2 and 3. The total bimonthly changes in submerged weed coverage of the lake area are expressed in coverage·ha^{-1}, as they occurred over the sampling period (Fig. 1).

From these results it is clear that peak growths occurred in March 1990 shortly after the introduction of the grass carp into the Florida Lake. A marked decline in weed standing crop had already taken place in the lake in May 1990, three months after the release of the grass carp when the total weed standing crop was reduced to 38% of the original densities as measured in March 1990. This dramatic reduction of *P. pectinatus* (25%) and *Lagarosiphon* (58,9%) cannot be explained by the feeding activity of the grass carp alone, but may partly be due to the random quantitative sampling programme of the weeds during the initial stages of the project, when irregularly dense patches of both plants might have affected the sampling, and thus the standing crop, to some extent. The change of season from late summer to early winter, with the corresponding drop in water temperatures, and the progressive, natural dying off of the plants, might also have affected this decline in standing crop of the weeds.

With the onset of spring (September 1990) and summer (November 1990) and the commencement of growth of these weeds, the effectiveness of the weed-eating ability of the grass carp clearly became evident (Table 2). It was only in late summer (January 1991) that the standing crop of *P. pectinatus* in the lake again showed a definite increase to 8 m·t with *Lagarosiphon* spp. increasing to 1 m·t (Table 2). The peak growths of both plants which had been experienced during the previous years did not, however, materialise again.

Discussion

In the establishment of the possible densities of the grass carp needed to control *P. pectinatus* and *Lagarosiphon* in the Florida Lake, a number of factors had to be taken into consideration. Most of the literature available on stocking densities of the grass carp deals with work done on an experimental basis in small ponds. Stocking densities used by these research workers vary considerably. Stott and Robson (1970) used stocking densities of 1 416 to 2 508 grass carp·ha^{-1} at an estimated fish biomass of 238 to 959 kg·ha^{-1} in experimental ponds to control a number of submerged water weeds, including *P. pectinatus*. Kilgen and Smitherman (1971) found a stocking density of 100 grass carp·ha^{-1} to be sufficient to control *Chara* spp., *P. diversifolius* and *Myriophyllum spicatum* in experimental ponds at Auburn, Alabama. Edwards and Moore (1975) stocked grass carp at 350 to 650 kg·ha^{-1} in drainage canals in New Zealand to control *Nasturtium officinale* and *Callitriche stagnalis*. Beach et al. (1976) used 50 grass carp·ha^{-1} to control *Hydrilla verticillata* in 3 lakes in central Florida, USA while Osborne and Sassic (1979) succeeded in controlling *H. verticillata* by stocking densities of only 13 grass carp·ha^{-1}. Gasaway and Drda (1977) found grass carp stocking densities of 116 to 298 fish·ha^{-1} sufficient to control vegetation such as *Nymphoides aquaticum, Nymphar macrophylla, Brasenia schreberi* and *Nymphaea odorata*. By using 50 fish·ha^{-1} Krzywosz and Radziej (1980) not only controlled, but eradicated the water weeds *P.natans, P. luceus, P. pectinatus, P. perfoliatus* and *P. crispus* completely from the Dag-Weilki Lake in Poland. Mitchell (1980) and Shireman and Maceina (1981) used 26 to 52 and 1 985 grass carp·ha^{-1}, respectively, to control a variety of weeds in lakes in New Zealand. It was against this background that stocking at a density of 86 grass carp·ha^{-1} (Schoonbee et al., 1985) was first used in Germiston Lake, but as a result of its effectiveness there, the numbers of the grass carp were reduced to a stocking density of 35 fish·ha^{-1} in Florida Lake, with promising results, as the present results indicate. The lower stocking density of grass carp in Florida Lake compared to that in Germiston Lake was further motivated by the experience gained at the Germiston Lake by Schoonbee et al. (1985), so that the chances of over-exploitation of the aquatic weeds in the lake would be minimised. Other factors which also influenced the decision on stocking density were that allowance had to be made for initial predation of some of the juvenile grass carp by fish-eating birds, black bass, perch and catfish as well as future mortalities caused by boats and anglers.

Comparisons of the effectiveness of the triploid form of *C. idella* with the normal fertile form as used in the Germiston Lake, indicate that the triploid fish are certainly not inferior in their ability to control submerged aquatic weeds. The impact of the grass carp on the entire lake ecosystem does, however, need to be evaluated. According to the literature, there is great conflict concerning the effect of the grass carp on water quality. Lembi et al. (1978) observed moderate increases in nutrient concentrations in the water with no changes or decreases in primary production or chlorophyll *a* values. Terrell (1975) stated that, although only 50% of the food of the grass carp is digested, the P and N contents of the partly digested plants undergo temporary fixation in the bottom sediments, suggesting that the grass carp would cause no significant increase in eutrophication levels. Mitzner (1978) suggested that increased fertility caused by the grass carp waste could conceivably result in blue-green algae blooms, which would be more detrimental to the lake than aquatic weeds. Owing to its short duration, no conclusive deductions can yet be drawn from the present study concerning the effect of the grass carp on the water quality of the Florida Lake. To date, no significant changes have been observed. Some development of a *Microcystis* bloom has, however, occurred since November 1990 while the chlorophyll *a* values measured during the survey progressively increased after the introduction of the grass carp into the lake from an initial low of 0,029 $\mu g \cdot \ell^{-1}$ (August 1990) to 23,650 $\mu g \cdot \ell^{-1}$ (January 1991). The release of partly digested plant material into the lake by the grass carp may hold some advantages for some fish species as it returns plant nutrients to the ecosystem which, in turn, can stimulate the secondary productivity of the lake and therefore also the benthic feeding fish life.

Results obtained have already shown that the grass carp might have some negative effects on population numbers of certain weed-eating birds e.g. the coot *Fulica cristata*, the Egyptian goose *Alopochen aegyptiacus*, and the yellowbilled duck *Anas undulata*. Owing to the removal of the weeds from the lake, small fishes became more exposed to fish-eating birds like the reed cormorant *Phalacrocorax africana* and the whitebreasted cormorant *P. carbo* which have both increased in numbers at the lake following the clearing of the lake surface area.

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