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Control of macrophytes by grass carp (*Ctenopharyngodon idella*) in a Waikato drain, New Zealand

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Abstract Hornwort (*Ceratophyllum demersum* L.) and other aquatic macrophytes have historically been mechanically removed from the Rangiriri drain and Churchill East drain to maintain drain efficiency. As an alternative control method for the high plant biomass that accumulates at the end of summer, the effect of stocking diploid grass carp (*Ctenopharyngodon idella* L.) on the aquatic vegetation was evaluated in these Waikato drainage systems. At the start of the trial, both drains had a low diversity of aquatic macrophytes, and of the nine species (including the emergents), seven were exotic. Two months after grass carp were released to Churchill East drain (the treated drain) the four submerged and floating macrophyte species became scarce in the main drain. Over the same period, these species increased in biomass in Rangiriri drain (the untreated drain), where hornwort became dense and surface-reaching and remained so for the duration of the trial. However, grass carp did not control submerged vegetation in smaller side drains or the shallow, upper parts of the main drain, or the marginal sprawling species and emergent species. The cost of leasing the grass carp was similar to the cost of clearing the drains mechanically, but grass carp provided continuous weed control. However, subsequent to this trial, 62 dead grass carp were found in Churchill East drain in February 2001, and weed cover subsequently increased. This illustrates that grass carp management in New Zealand agricultural drains can be problematic due to periodic fish kills.

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INTRODUCTION

The Ministry of Agriculture and Fisheries (MAF) imported grass carp (*Ctenopharyngodon idella* L.) from Hong Kong into New Zealand in 1971 to evaluate their potential for biological control of aquatic weeds (Rowe & Schipper 1985). New Zealand trials on aquatic weed control in Lake Parkinson and the Waihi Beach Reservoir (Mitchell 1980; Rowe & Champion 1993), Elands Lake (Clayton et al. 1995), and Lake Waingata (Rowe et al. 1999) demonstrated that grass carp could eliminate virtually all aquatic plants in discrete, static water bodies. The potential for restoration of lakes dominated by exotic macrophytes was demonstrated in Lake Parkinson where the *Egeria densa* (oxygen weed), was eradicated and native aquatic plants recovered naturally from seed banks following removal of grass carp (Tanner et al. 1990).

In flowing water such as the channelised Mangawhero Stream, grass carp also effectively eliminated all vegetation (Rowe & Schipper 1985). Edwards & Moore (1975) reported effective aquatic vegetation removal in a drain that flowed into the Awakaponga Stream (Bay of Plenty). We recently visited this site and found a well-oxygenated, clear, cool, spring-fed channelised waterway with high biodiversity including many freshwater crayfish (*Paranephrops planifrons*) more characteristic of a

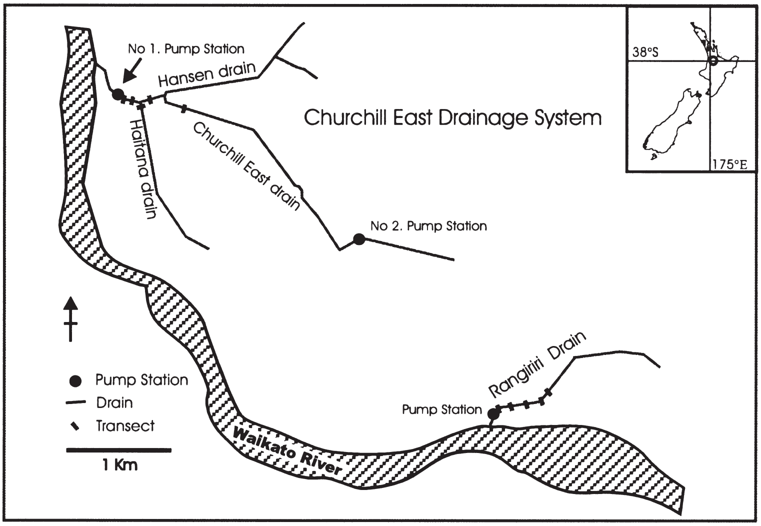

Fig. 1 Location of the treated Churchill East drain (with grass carp, *Ctenopharyngodon idella*) and the untreated Rangiriri drain (without grass carp) in the lower Waikato, North Island, New Zealand.

natural stream rather than a drain. In New Zealand agricultural drains however, most grass carp releases have been unsuccessful as grass carp in these systems suffer frequent fish kills from low oxygen, acid pH, and predation. Simpsons drain, Hauraki, was stocked at least 3 times, with up to 250 fish ha^{-1}, but the fish reduced weed biomass only temporarily before they were killed, apparently by unfavourable conditions (Rowe & Schipper 1985). Low pH (2.4) and low dissolved oxygen concentration (0.8 mg $litre^{-1}$) were recorded in the drain in December 1997 (NIWA unpubl. data). In the Aka Aka-Otaua drainage system, containment of fish was a problem, and at least 1000 fish escaped into the Waikato River from a MAF trial (McDowall 1984). Some fish from this escape might still survive, as a grass carp that exceeded 21 kg was caught in Lake Whangape in 1998 (Wells 1999). This trial was the start of a MAF research programme of weed control by grass carp in drains, but following this fish escape these trials were abandoned. Consequently, little is known of the use of grass carp in New Zealand drains or their impacts on biodiversity in such environments.

Much information is known about outcomes of using grass carp in other environments in New Zealand (Rowe & Schipper 1985) and overseas (Cassani 1996), but concerns have been raised about their potential for cumulative impacts on biodiversity and on native birds and fish from widespread multiple releases (Clayton et al. 1998). This is increasingly important as grass carp have become commercially available in New Zealand and are actively promoted for use in all kinds of waterways for macrophyte control. However, managers require approval from the Minister of Conservation before introducing grass carp to a new site. The Minister must decide if the risk that grass carp pose to the natural values (particularly biodiversity) in the proposed area is acceptable (Department of Conservation 1999).

This paper reports the macrophyte response to grass carp in a Waikato drain and was part of a wider study seeking to assess the impact of grass carp on biodiversity of fish, birds, and invertebrates (Bannon 2001). In addition, the aim of the grass carp manager (New Zealand Water Management) to maintain plant biomass at c. two-thirds of the levels without grass carp was examined.

STUDY SITES

Two drains were selected in the lower Waikato River catchment c. 24 km north-west of Huntly, North Island, New Zealand (37°16.1′S; 174°55.5′E; Fig. 1). Grass carp were released into Churchill East drain (the treated drain), which had 9 km of drains within the Churchill East drainage system, with c. 2.5 km of main drain (c. 3 ha in surface area) between two pump stations (Fig. 1). The upper section of the Churchill East drain is shown as the Ngariohe Stream on the NZMS 260, map number S13 (1996). The Rangiriri drain was selected as the control, and is referred to as the untreated drain. Both drains discharged into the Waikato River via pumping stations.

The treated drain had a catchment area of 1371 ha, consisting of 720 ha of pastoral hills, 178 ha of developed dairying flat land, and 473 ha of swamp area on poorly drained alluvial soil (Soil Bureau 1954). It discharged to the lower Waikato River during periods of rain through a float level controlled pump with a capacity of 4800 litres s^{-1}. The pump station prevented live grass carp escaping to the Waikato River. The drain appeared to be more suited for grass carp survival than most other Waikato drains as it was large (up to 13 m wide and often greater than 1 m deep), had little peat in the catchment that might yield water of low pH, and had little horticultural land with associated pesticide usage.

The untreated Rangiriri drain was 6 km south-east of the treated drain, and was smaller with only 1 km of open channels in a lowland catchment of 259 ha. The pump station also had a smaller capacity (900 litres s^{-1}). The catchment had similar soils to the treated drain comprising 94 ha of swamp. The remainder was in pasture and 2 ha of watermelons.

The treated drain supported brown bullhead catfish (*Ameiurus nebulosus*), shortfinned eels (*Anguilla australis*), goldfish (*Carassius auratus*), rudd (*Scardinius erythrophthalmus*), common smelt (*Retropinna retropinna*), and mosquitofish (*Gambusia affinis*) (Bannon 2001), indicating that it was a relatively suitable habitat for coarse fish. The untreated drain had a large population of brown bullhead catfish and some shortfinned eels and goldfish (Bannon 2001). Both drains also had a history of aquatic weed problems, with *Ceratophyllum demersum* L. the dominant nuisance species (K. Holmes, Churchill East drain manager pers. comm.). In addition, the treated drain had an extensive sprawling marginal vegetation of *Glyceria maxima* (reed sweet grass), but this species was not present in the untreated drain.

METHODS

Water quality and pre-trial weed removal

Dissolved oxygen, water temperature, and pH were measured 20 cm below the water surface at three permanently marked, equally spaced locations within 500 m of the lower pump station on six occasions. The recordings for each drain were made between 1400 and 1600 h on the same day except in June, when water quality in the treated drain was measured on 17 June 1999, before measurements were made in the untreated drain (24 June 1999). A data logger placed in each drain gave spurious results, probably the result of rapid fouling that is expected in drains. Nevertheless these data are useful for a general overview of water quality in the treated and untreated drains during the trial.

Before grass carp were released, most of the biomass of aquatic macrophytes that had accumulated during the previous summer was removed by a mechanical digger in May and early June 1999 to prevent flooding in the subsequent winter.

Grass carp release

On 24 June 1999, 250 diploid grass carp were released into the treated drain. Before release, the fork lengths (FL) of all carp were measured, and 123 carp were weighed. Weights of the 127 unweighed carp were calculated using the weight-length regression model $Y = -10.62 + 2.914X$, where Y = the natural logarithm of weight in g, and X = the natural logarithm of length in mm ($N = 123$, $r^2 = 0.971$, $P < 0.001$). The mean FL of grass carp at release was 342 mm and mean weight was 485.5 g.

The total weight of grass carp at release was estimated to be 121 kg, equivalent to 40 kg ha^{-1} (83 fish ha^{-1}) in the c. 3 ha of drain between the pump stations. Assuming that only the lower 1.5 ha of the drain was suitable for grass carp, as weed was not controlled elsewhere, the realised stocking density could have been up to 80 kg ha^{-1} (166 fish ha^{-1}).

Three-dimensional analysis of macrophyte cover

To evaluate the space occupied by macrophytes in three dimensions, five permanently marked 1-m-wide belt transects were selected per drain to represent the range of channel and vegetation types present. In the untreated drain, transects were c. 50 m apart, and in the treated drain they were c. 200 m apart (Fig. 1). Each belt transect was sampled using a 1 m^2 quadrat placed at 1-m intervals. Water depth, plant species, heights (or length if the water was flowing), and cover were recorded for each quadrat. The vertical distribution of plants was also recorded to enable the profiles of transects to be evaluated. This was necessary as much of the vegetation formed surface mats, growing into the channel from the margins with open water beneath. The transects were monitored 3 times: (1) in mid June 1999, before grass carp were released but after mechanical removal of the aquatic macrophytes; (2) in September 1999, 2 months after grass carp release; and (3) in January 2000.

The mean cover of each plant species was calculated for the five transects per drain.

Differences between the drains were compared using a *t*-test of ranked differences in cover between June 1999 and January 2000. The *t*-test was performed on the ranks of the differences because of extreme values. Between-drain comparisons were not made for species present in only one treatment. For example, reed sweet grass was recorded in the treated drain only so an analysis of variance was made on the pre- and post-treatment data for this species to compare differences before and after release of grass carp. Floating species data were not included in this analysis because they were not adequately sampled by 1-m-wide transects because of their irregular distribution.

Two-dimensional analysis of macrophyte cover

To evaluate the surface area occupied by surface-reaching macrophytes and floating species, the area of plant cover was recorded in 20-m lengths of the drains, each centered on a transect. This was done to check that we had representative transect data, and to include uncommon plant species and those with markedly clumped or irregular distribution patterns. The hypothesis that the means of water-surface cover for each macrophyte species was not different between the drains was determined by analysis of variance.

Biomass of submerged macrophytes

The area of maximum *C. demersum* biomass within 5 m of each transect was subjectively selected and then sampled by cutting a 1 m^2 quadrat. Harvested samples were dried to constant weight in a forced air-drying oven at 80°C, and total dry weight and species percentage composition calculated. Mean species dry weights ($N = 5$) were compared between drains.

RESULTS

Grass carp and water quality

Fifteen grass carp were recaptured by electric-fishing on 22 March 2000, 272 days after their release, and their weights and lengths were measured. Assuming no mortality or escape, and c. 3 ha of suitable habitat, this equates to a maximum biomass of grass carp of c. 233 kg ha^{-1}, which was almost 6 times greater than the original stocking density. If only the lower half the drain (c. 1.5 ha) was suitable habitat, the grass carp biomass was 466 kg ha^{-1}.

Dissolved oxygen concentrations were greater in the treated drain (22–132%) than in the untreated drain (3–91%). Water temperatures (8–23°C) and pH (5.3–7.5) did not vary consistently between drains during the trial (Table 1).

Macrophytes

Before grass carp release

Vegetation in both drains in June 1999 was similar following mechanical removal of macrophytes, with little surface vegetative cover remaining ($P = 0.185$; Table 2). When subsurface vegetation was included, 28–32% of the surface was covered with vegetation (Table 3). Two submerged macrophyte species were found in the drains. Of these, the exotic *C. demersum* was much more abundant than the native *Potamogeton ochreatus*. Marginal emergent vegetation differed between drains. *Glyceria maxima* was dominant in the treated drain but was absent

Table 1 Means of water quality variables in the treated Churchill East drain (with grass carp, *Ctenopharyngodon idella*) and the untreated Rangiriri drain (without grass carp), Waikato, New Zealand. All measurements were made 20 cm below the water surface between 1400 and 1600 h on the same day, except for the June measurements (treated drain, 17 June; untreated drain, 24 June). Measurements were at three permanently marked, equally spaced sites within 500 m of the lower pump station; means were calculated from one measurement at each of the three locations.

	Dissolved oxygen (%)		Water temperature (°C)		pH	
Month	Treated	Untreated	Treated	Untreated	Treated	Untreated
Jun 1999*	41	21	14.0	8.3	5.5	6.4
Sep 1999	22	41	14.8	16.2	5.3	5.5
Nov 1999	38	3	18.2	17.2	6.9	7.1
Dec 1999	81	30	21.4	17.5	7.5	7.4
Feb 2000	69	14	22.8	22.0	7.2	6.9
Apr 2000	132	91	19.2	17.8	7.0	7.2

*June survey was made on 11 June 1999, 1 week after mechanical removal of aquatic macrophytes, but before the release of grass carp on 24 June 1999.

from the untreated drain (Tables 2 and 3). Maximum biomass of submerged plants was low in both drains in June 1999 (30–50 g dry weight m^{-2}; Table 4). At the start of the trial, *Azolla pinnata*, *Lemna minor*, and *Spirodela punctata* covered <3% of both drains (Table 2), and were found among other macrophytes protected from the flow.

After grass carp release

By late January, the treated and untreated drains had become quite different in their vegetative composition and structure (Fig. 2), and there was much less surface cover in the treated drain than in the untreated drain ($P < 0.01$; Table 2). The surface cover of all rooted macrophytes in the untreated

Table 2 Mean percentage of the water surface occupied by aquatic macrophytes in five 20-m-long sections in the treated Churchill East drain (with grass carp, *Ctenopharyngodon idella*) and the untreated Rangiriri drain (without grass carp), Waikato, New Zealand. Differences between means for the treated and untreated drains were determined by analysis of variance.

Taxa of aquatic macrophytes	Mean % area covered by macrophytes: Jun 1999 Treated*	Untreated	P	Sep 1999 Treated	Untreated	P	Jan 2000 Treated	Untreated	P
Floating									
Azolla, *Lemna*, and *Spirodella*	2.68	0.33	<0.01	0.77	0.00	0.17	0.00	18.50	0.02
Rooted submerged									
Ceratophyllum demersum	6.66	1.78	0.17	2.17	1.67	0.83	0.00	58.67	<0.01
Potamogeton ochreatus	0.13	0.00	0.04	0.00	0.00	1.00	0.00	0.00	1.00
Rooted emergent									
Glyceria maxima	1.98	0.00	0.02	2.45	0.00	0.02	12.70	0.00	<0.01
Ludwigia peploides	0.04	0.97	<0.01	0.00	0.33	0.35	0.17	2.38	0.03
Myriophyllum aquaticum	1.18	1.47	0.70	0.42	0.00	0.35	0.96	1.04	0.93
Paspalum distichum	0.15	1.20	0.20	0.17	1.40	0.19	1.25	2.75	0.52
Polygonum salicifolium	0.12	0.30	0.11	0.17	0.17	0.96	0.00	0.18	0.19
All rooted macrophytes	10.25	5.72	0.19	5.37	3.56	0.60	15.08	65.01	<0.01

*June survey was made on 11 June 1999, 1 week after mechanical removal of aquatic macrophytes, but before the release of grass carp on 24 June 1999.

Table 3 Mean percentage cover of aquatic macrophytes throughout the water column in five 1-m-wide transects in the treated Churchill East drain (with grass carp, *Ctenopharyngodon idella*) and the untreated Rangiriri drain (without grass carp), Waikato, New Zealand. Differences between the rank order of cover for each species in June and January in the treated and untreated drains were determined with a *t*-test.

Taxa of aquatic macrophytes	Mean % cover: Jun 1999 Treated*	Untreated	Jan 2000 Treated	Untreated	P
Rooted submerged					
Ceratophyllum demersum	12.5	14.0	0.57	62.0	<0.01
Potamogeton ochreatus	4.42	0.48	0.00	1.42	0.19
Rooted emergents					
Glyceria maxima	6.86	0.00	15.9	0.00	–
Glyceria fluitans	0.00	0.01	0.00	0.00	–
Ludwigia peploides	1.89	4.70	0.28	6.27	0.19
Myriophyllum aquaticum	2.03	9.73	0.19	2.17	0.92
Paspalum distichum	0.13	2.17	0.08	5.61	0.01
Polygonum salicifolum	0.05	0.66	0.02	0.39	0.09
All rooted macrophytes	27.9	31.8	17.1	77.9	0.04

*June survey was made on 11 June 1999, 1 week after mechanical removal of aquatic macrophytes, but before the release of grass carp on 24 June 1999.

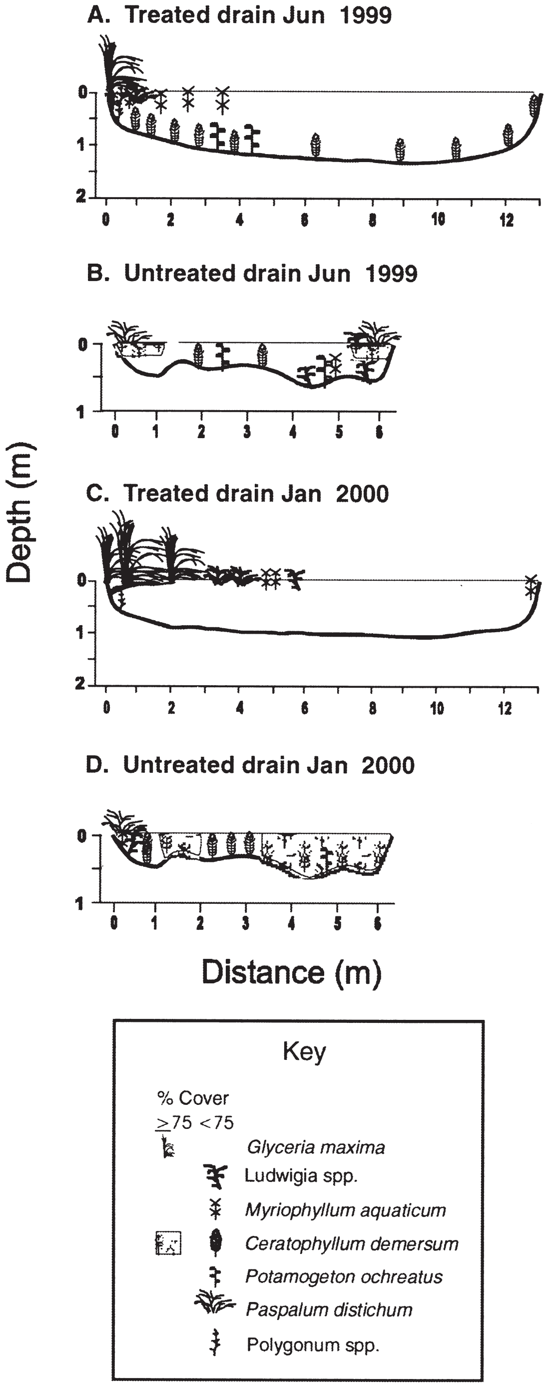

Fig. 2 Stylised profiles drawn from representative transects of two Waikato, New Zealand, drains with (treated) and without (untreated) grass carp, *Ctenopharyngodon idella*. June sampling was undertaken 1 week after mechanical removal of aquatic macrophytes, but before the release of grass carp.

drain had increased from 6 to 65% between June 1999 and January 2000, compared with the 5% increase (from 10 to 15%; Table 2) in the treated drain. Vegetation through the water column in the untreated drain had increased from 32 to 78% cover ($P = 0.04$; Table 3, Fig. 2B,D), with *C. demersum* still the dominant submerged species. Maximum biomass of submerged species had increased on average from 33 g dry weight m^{-2} in June 1999 to 173 g dry weight m^{-2} in January 2000 (Table 4). Floating species had increased c. 4-fold, from 0.3 to 18% average cover (Table 2) and the emergent species *Paspalum distichum* and *Ludwigia peploides* were now the co-dominant emergent marginal plants.

In contrast, the treated drain had virtually no submerged vegetation in January 2000 (Table 3), and the macrophyte biomass was too small to record (Table 4, Fig. 2C). The surface cover of floating species also declined from 2.7% to nearly zero, in contrast to the emergent species *G. maxima*, which increased from 2 to 12% cover (Table 2) and formed a prominent margin along most of the drain. Other marginal species persisted and although their mean percentage cover increased, the difference was either too small or inconsistent to be statistically significant (Tables 2 and 3). These major differences between drains in vegetation abundance and structure are also shown in the stylised profiles drawn for January (Fig. 2).

Changes recorded on the transect sites were representative of each drain. For example, the upper parts of the treated drain were also fringed with *G. maxima* and had no submerged plants except within c. 500 m of the upstream No. 2 pump station. The percentage cover of vegetation was much higher in the upper parts of the main drain as the drain was shallower and narrower than the lower portion, and therefore marginal vegetation occupied proportionately more of the channel. Differences were seen in the two side drains off the treated main drain (and within c. 500 m of the No. 2 pump station in the main drain). Hansen drain (c. 3 m wide and 0.5 m deep), a side drain with no physical barrier to grass carp (Fig. 1), retained a 100% surface cover of *C. demersum* for the duration of the study period. Also, shallow parts of Haitana drain supported dense *Myriophyllum aquaticum* (parrots feather) in January 2000.

Subsequent to this study, the site was visited on 25 February 2001 and 62 dead grass carp were found, mostly near the screens of the No. 1 pump station, but also up to 1 km upstream. We do not know exactly when the fish died or how many grass carp remain, but it is likely that most if not all died c. 10 days previously. A resurvey of the vegetation of the transects on 21 March 2001 and observations of macrophytes in the main drain up to the No. 2 pump station found marked regrowth of the marginal *G. maxima* and the floating species *Lemna minor* and *Azolla pinnata*, as well as some recovery of the submerged vegetation (*C. demersum* in particular).

DISCUSSION

Weed control using grass carp

The grass carp thrived and removed almost all of the submerged aquatic vegetation from the lower portion of the treated Churchill East drain between July 1999 and December 2000 (Bannon 2001). *C. demersum*, the dominant submerged species before treatment, was completely suppressed in the treated drain but regrew in the untreated drain after mechanical clearance. Floating plants became scarce in the treated drain probably by direct consumption, although their habitat also became unsuitable with the removal of submerged macrophytes that provided shelter and prevented them from being washed down stream. Much marginal vegetation remained in the treated drain, and appeared as a solid block of vegetation when viewed from above the surface. However, there was open water beneath the surface vegetation in depths greater than c. 0.7 m (Fig. 2C).

The marginal plant, *G. maxima*, was the dominant species and was apparently not eaten by grass carp in Churchill East drain. In contrast, Rowe & Schipper (1985) reported *G. maxima* was eaten before *C. demersum* in the Mangawhero Stream (Aka Aka-Otau) by large grass carp (400–500 mm). As grass carp become larger they reportedly are capable of eating fibrous plants more readily (Opuszynski 1972; Rottmann 1977), so it is likely that if the fish of the Churchill East drain were larger they may have eaten *G. maxima* and other marginal species. *G. maxima* was removed from Churchill East drain using a mechanical digger in autumn 2000 to open up the channel.

Grass carp did not control aquatic plants in the side drains or in the upper 500 m of the main Churchill East drain. Hansen drain showed no sign of fish feeding during the study period; *C. demersum* persisted with a 100% surface cover. Transect data for these side drains were reported by Kessels & Associates (2000) and confirms these observations. In Florida, grass carp seldom moved into shallow canals (<1 m deep) even when this was their only food source (Sutton et al. 1986). In New Zealand drains, grass carp tended to keep away from the shallowest and narrowest areas of drains, though weeds were eventually eliminated from these places when all other aquatic vegetation was eaten (Rowe & Schipper 1985). Hansen drain may be unsuitable for grass carp as it is shallow (0.5 m), and had low oxygen levels (0.5–0.9 mg litre^{-1} on 22 December 1999). Additionally, fish access was through a 5-m-long culvert, which could have discouraged carp from entering the drain.

Economics

The economics of drain management were considered by reference to the financial records for

Table 4 Maximum biomass of submerged macrophytes in the treated Churchill East drain (with grass carp, *Ctenopharyngodon idella*) and the untreated Rangiriri drain (without grass carp), Waikato, New Zealand.

	Maximum biomass of submerged macrophytes (g dry weight m^{-2})					
	Jun 1999		Sep 1999		Jan 2000	
Site	Treated*	Untreated	Treated†	Untreated	Treated†	Untreated
1	0	76	0	79	0	224
2	162	24	0	71	0	190
3	0	3	0	42	0	207
4	0	23	0	53	0	149
5	72	38	0	119	0	96
Mean	47	33	0	73	0	173

*June survey was made on 11 June 1999, 1 week after mechanical removal of aquatic macrophytes, but before the release of grass carp on 24 June 1999.
†Insufficient macrophyte material to sample.

Table 5 Annual costs of drain cleaning, pumping, and maintenance compared with grass carp (*Ctenopharyngodon idella*) leasing for controlling aquatic macrophytes in c. 3 ha of the Churchill East drainage system (side drains not included), Waikato, New Zealand.

Activity	Range of costs for the last 5 years (NZ$)
Drain cleaning by digger	4810–7950
Electricity for pumps	7310–15510
Maintenance	1570–6590
Screen cleaning	180–3270
Grass carp (annual lease in 1999)	4390

drainage expenditure and discussions with Mr K. Holmes, the Drainage Association's treasurer and drain manager. Income from a drainage tax on landowners was c. NZ$35 000 per annum and has been maintained at the same level for the past 9 years. The cost of drain clearance using a digger is similar to the grass carp lease costs (Table 5). Additional savings with grass carp could be made through the reduced need for screen cleaning, and reduced cost of electricity for pumping, as the pumps operate more efficiently if the screens are not blocked by aquatic vegetation. Even with grass carp, mechanical clearing would still be required in the side drains and the margins and upper reaches of the main drain to control *G. maxima*. Furthermore, sporadic fish kills such as the one recorded subsequent to this study, can have a major effect on the economics of grass carp for weed control in this type of drain and indicate the unpredictability of managing grass carp in drains.

Alternative aquatic macrophyte control options include the use of a weed cutting boat costing NZ$750 ha^{-1} per cut (P. Anderson, Works Supervisor, Bay of Plenty Regional Council pers. comm.), which could be less expensive (NZ$2250 $year^{-1}$ for the 3 ha). Mr K. Holmes suggested that if grass carp continued to keep the lower section of the main drain clear from year to year, they would be worth additional costs because of benefits in the efficient operation of the drainage system. He also considered grass carp preferable to other methods because the alternatives involve significant overheads with administration, letting of contracts, supervision and payments, and an element of unreliability regarding availability of a contractor when the drains are required to be free of weeds. Ecological considerations were not factored into the cost-benefit analysis for these sites.

Macrophyte diversity

Macrophyte diversity in the two drains was low, with only nine aquatic species recorded, including the marginal emergent species. Grass carp reduced the number of macrophyte species by four and would eventually be likely to remove the rest if they survived, as older fish include fibrous plant species in their diet. The depauperate range of macrophyte species present in both drains at the start was typical of a large number of drains the authors have observed throughout the North Island (NIWA unpubl. data). Of the nine aquatic macrophytes identified, seven were alien species common in the North Island and in many instances are actively spreading (Johnson & Brooke 1989). None of these macrophytes are of national or regional significance. The two native species, *Potomageton ochreatus* and *Polygonum salicifolium*, are common throughout New Zealand.

If grass carp are released into many drains in the area, then their effects on itinerant species such as ducks and geese could be widespread, displacing birds from areas where macrophytes have been removed to more sensitive areas where macrophytes remain. However, it is likely that most drains will not be suitable for grass carp, as they are either too shallow, periodically too low in dissolved oxygen or pH for grass carp survival, are not suitably secure sites, or have high biological values that would not meet the Department of Conservation criteria for approval to release grass carp.

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