contribution to the total diet because they contribute only 3% of the total landings.

As fishing continues to develop in New Zealand and the accumulated stocks of the older larger survivors of the long-lived species are reduced, the average size of the fish and therefore the average concentrations of mercury in those which are landed will also be reduced. But, as the concentrations are already substantially below those which are acceptable elsewhere, there is no reason to regard New Zealand fish as unsafe for human consumption.

ACKNOWLEDGMENTS

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EFFECT OF JET BOATS ON SALMON EGGS

A. J. SUTHERLAND and D. G. OGLE

Civil Engineering Department,
University of Canterbury, Christchurch,
New Zealand

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ABSTRACT

The passage of jet boats through spawning areas can kill salmon eggs buried in the river bed. By using a jet boat on the Ashley River the pressure gradients created in a redd were determined. At the maximum boat speed investigated ($11\ m.s^{-1}$) gradients up to $9.32\ kPa.m^{-1}$ were recorded. The induced water velocities through the gravel were then estimated from the equation of motion and reproduced in a gravel-filled tube in the laboratory. For the test conditions discharge velocities ranged from $0.18–0.3\ m.s^{-1}$. Studies of the effect of these flows on salmon eggs revealed fatality rates of up to 40% at their most critical stage on the ninth day of development.

INTRODUCTION

Very little quantitative information is available about the effect of a jet boat on the water and on the stream bed over which it travels. In spite of this, there have been many claims that the passage of jet boats through spawning areas is detrimental to and can even kill fish eggs that may be buried in the gravel of the stream bed. At the request of the New Zealand Jet Boat Association and with the support of the Department of Agriculture and Fisheries, an investigation was undertaken firstly to establish whether the passage of jet boats can harm fish eggs, and secondly to estimate the magnitude of such harm for a range of conditions typical of those in which jet boats operate.

The investigation was concerned only with the possibility of physical damage to the eggs. Other aspects such as damage to the nervous system of the developing embryo were not considered. The results indicate that consideration should be given to excluding jet boats from known spawning areas during the spawning season, approximately March to June of each year.

BACKGROUND CONSIDERATIONS

Quinnat salmon *Oncorhynchus tshawytscha* (Walbaum) were introduced to New Zealand waters at the beginning of this century and are now successfully acclimatised in rivers throughout the South Island. Their life-cycle has been documented by Flain (1971) and will be described only briefly herein.

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The adult fish migrate from the sea to the river-mouths, usually in mid March, in the third or fourth year of their lives. They return to their parent streams and commence spawning towards the end of April. The females dig nests (known as redds) out of the gravel river bed and lay their eggs in pockets within the redds; the males participate only during the mating sequence. The females subsequently cover the eggs with coarse gravel. Depending on the temperature of the water, the eggs hatch 40–50 days later. The young fish spend varying times in freshwater, the greater number leaving the parent stream at a very early age while some spend up to a year in fresh water. Very little is known about the fish after they enter the sea until they return to spawn.

The egg consists of an outer membrane and an inner yolk, separated by a watery fluid, the perivitelline fluid. The egg is relatively strong during the first two days of its life when the surrounding redd may still be in the process of construction. After approximately one third of the incubation period, the egg reaches a most delicate state as it undergoes gastrulation.

Jet boats are shallow- or moderate-vee planing hulls approximately 3–6 m long with a beam of from 1.5–2.5 m. Their propulsion system uses a pump to draw water from an intake in the hull and discharge it, as a jet, through a contracting orifice at the rear of the boat. Among the many advantages of this system is its ability to operate in water depths as small as 150 mm, enabling the boats to traverse the shallow headwaters of rivers where the salmon spawing grounds are found.

The passage of the boat gives rise to fluid pressures in the vicinity of the hull which are different from the normal hydrostatic pressure. In shallow water, these pressure fluctuations will propagate to the stream bed and through the water between the gravel particles. As the bow of the boat passes over a given point a positive pressure fluctuation occurs. This is followed by a sudden reduction in pressure caused by the jet intake and then by a pressure recovery. There may be further small fluctuations as the stern and the wash behind the boat move over the given point. Depending upon the boat's speed and length the fluctuations may occur over time intervals as short as 0.2 s.

To determine the conditions most harmful to salmon eggs a series of exploratory tests was conducted. Full details of these tests are given by Ogle (unpublished 1972). The eggs were subjected to high (± 6 m of water) static pressures and to oscillating pressures up to 60 Hz. They were also tested under a static load applied directly to the outer shell, by prolonged rotation, and by sudden accelerations and decelerations, including impact on a stone or sudden wedging between stones. The high and low static pressures and the pressure fluctuations had no adverse effect on eggs. Only the acceleration and deceleration tests resulted in significant fatality rates; the yolks were easily ruptured by the physical shock, especially on impact. Such impacts and yolk rupture, which is inevitably fatal, may occur in a redd if the egg is moved through the gravel by a water flow.

Pressure fluctuations caused by the passage of the jet boat will result in intragravel flows. It is shown here that, in shallow water, jet boats can create flows of sufficient strength to cause fatal impacts.

EXPERIMENTAL WORK

One approach to determining the effect of jet boat passage over eggs in a redd would be to place eggs in an artificial redd and to run a jet boat over it. However, the uncertainties in placing and recovering the eggs and in assigning the resultant fatalities to the passage of the jet boat precludes such an approach. A natural redd cannot be used for the same reasons. Thus the experimental work was done in two stages. First, a series of field tests to investigate the induced hydrodynamic conditions in an artificial redd and, second, laboratory tests in which eggs were placed in conditions which simulated those found in the field. From the results of these laboratory tests and a knowledge of the distribution of eggs within a natural redd (Hardy 1963), percentage fatalities associated with jet boat passages over a redd could be estimated.

FIELD TESTS

Because the eggs are particularly susceptible to impact, it was necessary to determine quantitatively the dynamic character, in particular the maximum velocities, of flows induced in the gravel bed by jet boats. To place instruments of sufficient sensitivity and dynamic response which can continuously record the flow velocity (including direction) at points in a gravel bed would be extremely difficult. It is more practical to measure the pressure fluctuations and from these to deduce the associated velocities using a theoretical model as described below.

Three artificial redds, 1 m long, 1 m wide, and 0.5 m deep and conforming to the measured composition (Ogle unpublished 1972) of an actual salmon redd, were constructed in the bed of the Ashley River immediately downstream of the bridge on State Highway 1. Pressure fluctuations within these redds were measured by five pressure sensors mounted in a common frame (Fig. 1). The frame was placed perpendicular to the line of boat travel at various positions within the redds and covered with a coarse screen before replacing the gravel. The screen prevented stones from touching the sensors.

The sensors were 18-gauge (0.52 mm) brass strips of rectangular shape rigidly supported at their ends. They were 100 mm × 16 mm and spaced at 125 mm, thus ensuring that average fluctuations over an area equivalent to that occupied by several stones (average size 18 mm) were measured and that localised pore pressure fluctuations were ignored. An electrical strain gauge mounted on the underside of each sensor provided a record of the strains induced by the pressure fluctuations acting on the upper surface of the strip. An amplifier and portable battery-operated

6-channel recorder completed the measuring system (Fig. 1). Each sensor was calibrated statically using the weight shown in Fig. 1 before and after every test run.

The boat used for all the tests was a standard production model "Hamilton Jet 20", 3.8 m long, with a Ford V4 motor. It was driven over the redd four times (twice upstream and twice downstream) for each speed at each of three lateral positions indicated in Fig. 2. Boat position 3 is equivalent to having the boat positioned at 1 with the frame containing sensors turned end for end and placed on the other side of the redd. Thus fluctuation measurements over the whole width of the redd were obtained with an overlap in the centre. This allowed checks for consistency to be carried out and any doubtful records discarded. Boat position 2 gave measurements over half the width of the redd for the boat passing along the centre line of the redd. The procedure was repeated for other water depths and with the pressure sensors at different distances below the gravel surface.

During each passage of the boat over the redd a trace of pressure against time was recorded for each of the five gauges. A typical trace can be seen on the recorder in Fig. 1. For any given boat speed, the time scale on the trace can be converted to a distance scale with origin at the bow of the boat. By combining all traces obtained from a particular elevation, usually nine spaced evenly across a line perpendicular to the line of boat travel, contour maps of equal pressure fluctuation could be drawn. A typical map (Fig. 3) shows a plan view of the fluctuations occurring at points on a horizontal plane at a given depth in the redd for a particular boat speed. There were several such maps for every boat speed, each map representing fluctuations at different distances beneath the gravel surface. Sufficient tests were performed to allow fluctuation gradients in three mutually perpendicular directions to be determined for a series of 6 boat speeds ranging from 1.5–11.0 m.s^{-1} in three different water depths: 150 mm, 300 mm, and 450 mm.

Preliminary analysis of the maps showed that maximum velocities (steepest pressure gradients) were likely to occur in one of two areas, either in the area of large positive fluctuations near the bow of the boat, or immediately behind the intake. Selected points in these areas were analysed for twenty two different combinations of boat speed, boat position (laterally relative to the redd), and water depth. At each point, fluctuation gradients as functions of time were deduced longitudinally along the forward line of boat travel, laterally away from the boat and vertically downwards. Vertical gradients were obtained by choosing two overlaying maps, the point under consideration being midway between them. Lateral and longitudinal gradients were obtained either from the map at that depth (if there was one) or from the average of the maps immediately above and below that point. These arrays of fluctuation gradients were used to deduce flow velocities through the gravel as a function of time.

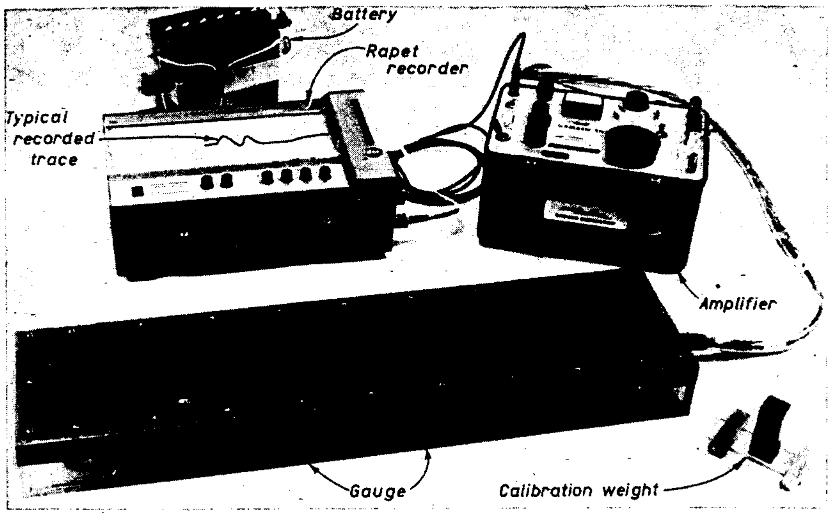

FIG. 1—Pressure sensing strips and recording equipment used to measure pressures induced by the passage of a jet boat in shallow water over an artificial salmon redd constructed in the bed of the Ashley River.

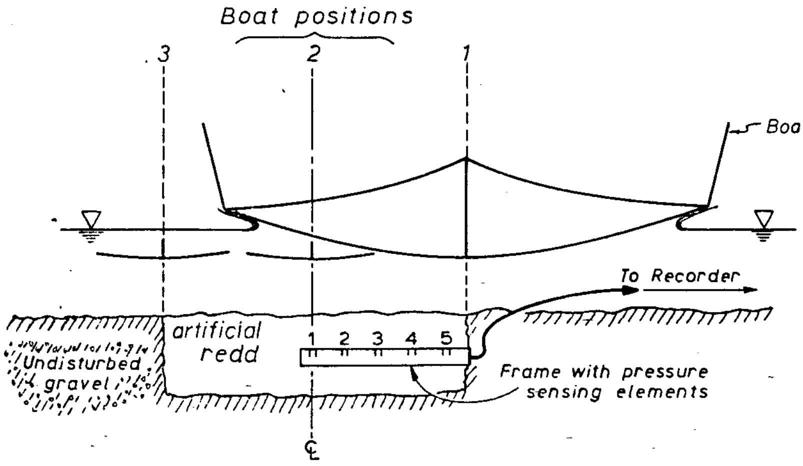

FIG. 2—Cross-section of artificial salmon redd, perpendicular to line of boat travel, at testing site on the Ashley River immediately downstream of the bridge on State Highway 1. Tests were made with the boat, shown in figure in position 1, in each of the three boat positions indicated.

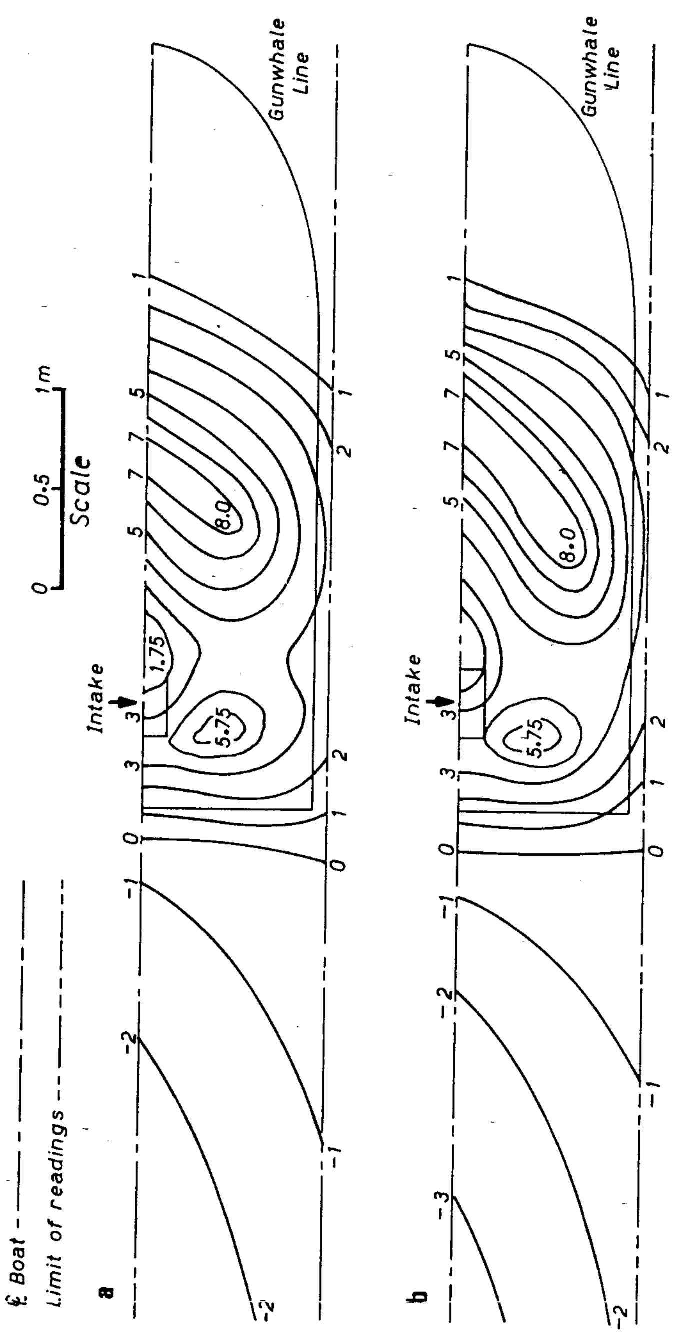

FIG. 3—Plan views of artificial redd showing contours of equal pressure fluctuation measured on a horizontal plane 130 mm beneath the surface of the redd. The fluctuations were induced by the passage of a jet boat in a water depth of 300 mm at speeds of 6.7 $m.s^{-1}$ (a) and 5.6 $m.s^{-1}$ (b). Values noted on the contours are to be multiplied by 0.25 to give pressure fluctuations in kPa.

FIG. 4—Gravel filled tube and constant head tank used in the laboratory to simulate the flow conditions deduced from field measurements of pressure fluctuations induced in an artificial salmon redd by the passage of a jet boat.

LABORATORY TESTS

Salmon eggs were subjected, in laboratory tests, to intragravel flows which simulated those deduced from the field tests. From the time of fertilisation until the day of testing the eggs were stored in special containers at the North Canterbury Acclimatisation Society's Silverstream Hatchery. The containers were made from 50-mm-diameter perspex tubing and were 60 mm high. They were placed in a rack where a steady gentle flow of water passed up through each container. Individual containers could be removed from the rack without disturbing the others. On the day of testing a container, supported in a cradle inside a 2-litre plastic bottle filled with water from the hatchery, was transferred to the laboratory. The eggs were then split into batches, each containing some 10–20 eggs, ready for testing.

Conditions in the redd were simulated in the laboratory by applying a pressure gradient across a 150-mm-diameter tube packed with gravel taken from one of the artificial redds built in the Ashley River. The tube was mounted adjacent to a head tank as shown in Fig. 4. The head tank provided a controlled flow of water through the sliding perspex gate into the gravel packed tube. Different pressure gradients, the range of which encompassed those gradients found in the field tests, could be applied across the tube by adjusting the water level in the head tank. When the flow reached a steady state, a batch of eggs was injected into the tube by means of the syringe shown in Fig.4. In the tube they passed around the gravel particles undergoing accelerations, decelerations, and impacts equivalent to those experienced by eggs in the river bed. On impact the eggs would thus experience the same shock mechanism as eggs in a redd. The water flow was continued after the eggs were inserted in the tube for periods of up to 1 min. The eggs were thus exposed to the flows for periods longer than eggs affected by the passage of a single jet boat. The chances of an egg being damaged are thus greater, and the laboratory results are therefore more representative of the effects of several passes by jet boats.

After such a test the eggs in the tube were examined and the fatality rate determined. Each day of testing included repeated tests, each with a new batch of eggs, at up to five different pressure gradients and a control test. As a check on the injection technique one of the batches of eggs was injected, using the same syringe and tubing, into the 150 mm diameter tube filled with still water. On each day these control tests showed negligible fatality rates.

Tests were performed on days 6, 7, 8, 9, 10, and 13 of egg development, new eggs being brought from the hatchery on each day. Percentage fatality as functions of the applied pressure gradient are shown in Fig. 5 which shows the ninth day to be most critical. Each point on the graph is a mean value of four or five repeated tests. There is no obvious explanation for the anomolous points taken on the eighth day.

ANALYSIS

The variation of velocity with time at a point in the redd can be deduced from the measured fluctuation gradients at that point by using the equation of motion for the fluid. The equation can be written as

$$-\frac{\rho g}{k}\vec{u} - \nabla p = \rho\frac{\partial \vec{u}}{\partial t} \qquad (1)$$

where ρ is the fluid density, g the gravitational acceleration, k the permeability of the redd, p the pressure fluctuation, ∇ the gradient operator, $\vec{u}$ the discharge velocity, and t time. The first term represents the resistance per unit volume offered to the flow by the gravel and embodies Darcy's Law. The second term is the pressure force per unit volume. On the right hand side is the mass acceleration product per unit volume from which the convective acceleration terms, which are expected to be small for the flows under consideration, have been neglected.

By finite differencing in time, using the initial condition of zero velocity and the measured fluctuation gradients, equation (1) can be solved in component form for $\vec{u}$ as a function of time. Laboratory tests with steady flows on a sample of gravel from a redd showed k to be velocity dependent. This dependence necessitated, at each time step, a trial and error solution for the new velocity. The analysis was performed by computer, the output being the discharge velocity as a function of time. Typical values ranged from 0.18–0.3m.s^{-1}. Actual fluid velocities within the redd will be higher than these by at least a factor equal to the reciprocal of the porosity of the gravel; for the redds examined this factor was 2.8.

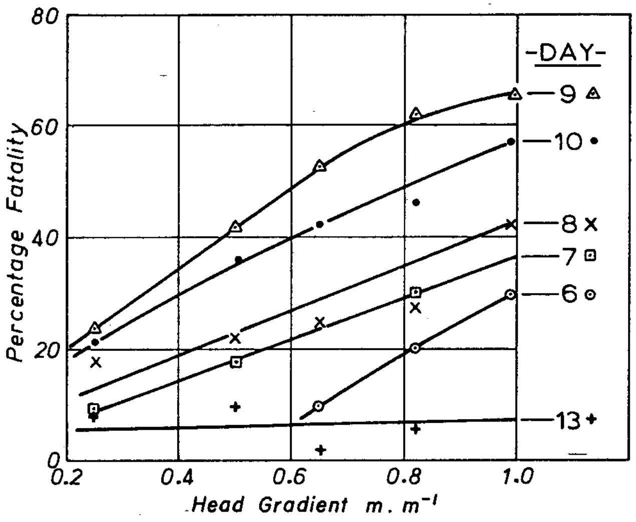

FIG. 5—Percentage fatality, during laboratory tests, of eggs of quinnat salmon *Oncorhynchus tshawytscha* as a function of applied pressure gradient. The eggs were injected into a gravel filled tube in which the flow conditions resulting from the passage of a jet boat over an artificial redd were simulated. The applied pressure gradient is plotted in terms of head. With the tests being done in water, 1.0 m.m^{-1} is equivalent to 9.81 kPa.m^{-1}.

To determine the effect of a given discharge velocity on eggs that may be in the redd, the gradient required to produce that velocity is calculated from Darcy's Law, using the experimentally determined values for k, and the expected fatality rate found from Fig. 5.

Taking, for a given boat speed and water depth, the maximum discharge velocities that occurred in the upper and lower half of the redd, a percentage fatality can be determined for each half. Work by Hardy (1963) allows the distribution of eggs with depth in a redd to be estimated. Combining this with the fatality rates found above, an overall percentage fatality occurring in a redd can be estimated. Table 1 summarises the results of these calculations and shows, for each tested water depth, the *maximum* overall percentage fatalities for the redd as a result of the most destructive boat speed at each depth.

The values are termed *maximum* overall percentage fatality because in deriving them it was assumed that

(i) all eggs in the redd were 9 days old (the most sensitive time, see Fig. 5),

(ii) that all the eggs in the redd were exposed to the maximum induced velocities at their particular depth.

TABLE 1—Maximum overall percentage fatalities of eggs of quinnat salmon *Oncorhynchus tshawytscha* subjected to pressure gradients induced in their redds by passages of jet boats in shallow water

Water depth (mm)	150	300	450
Boat speed ($m.s^{-1}$)	8.9	5.6	4.0
Fatality (%)	37	39	24

Table 1 thus shows values which may be higher than those caused by a single pass of a jet boat over a typical redd. Now, at certain times in the spawning season, there will certainly be redds with 9-day-old eggs exposed to jet boats and further, when a number of jet boats are operating, it is quite possible that many eggs will, during one pass or another, be subjected to velocities at least close to the maximum. Consequently the figures of Table 1 may not be as exaggerated as might at first be assumed in light of the two assumptions above.

CONCLUSION

This investigation has shown that jet boats are capable of killing salmon eggs. The numerical estimates obtained indicate that the passages by jet boats through spawning areas may cause significant loss of eggs (possibly 20–40%) in some redds. This figure must be regarded as being indicative only, because it reflects the worst possible combination of circumstances. However, if a number of jet boats are active in a spawing area, their cumulative effect may be such that these conditions could be approached.

In view of these results it is suggested that consideration be given to restricting the activities of jet boats in spawning areas during the spawning season.

The New Zealand Jet Boat Association has voluntarily adopted a policy among its own members, who comprise the majority of jet boaters, of not entering known spawing areas during the spawing season. The problem of restricting those who do not belong to the Association remains.

ACKNOWLEDGMENTS

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CONTROL OF WATER WEEDS BY GRASS CARP IN A DRAINAGE DITCH IN NEW ZEALAND

D. J. EDWARDS and E. MOORE

Fisheries Research Division, Ministry of Agriculture and Fisheries,
P.O. Ngapuna, Rotorua, New Zealand

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ABSTRACT

Two-year-old grass carp *Ctenopharyngodon idella* Val. were stocked at a rate of 350–650 $kg.ha^{-1}$ in a farm drainage ditch in the Bay of Plenty, New Zealand. During the months December to April the fish greatly reduced the standing crop and percentage cover of the weeds *Callitriche stagnalis* Scop. and *Nasturtium officinale* R.Br., but had no effect on *Polygonum decipiens* R.Br.

INTRODUCTION

Pond studies have shown that many weed species which cause problems in New Zealand waterways are eaten by grass carp (Chapman & Coffey 1971, Edwards 1974). Successful weed control in a natural water body is, however, also dependent on factors other than weed palatability, notably rates of weed growth and fish feeding activity, and fish stocking density.

Edwards (1973) reported that, even when abundant palatable weed is present, young grass carp kept in aquaria will eat invertebrates and fish fry. Studies in Poland (Fischer 1970, 1972, 1973) showed that grass carp weighing up to 400 g eat a mixed diet of animal and plant food, and that growth is retarded when animal food is not available. Preference for animal food in a natural environment could reduce the potential for weed control.

It was therefore important to test the potential of grass carp for weed control in a New Zealand waterway where weeds are a problem, and where aquatic animals are also present. An experiment was designed to establish the degree to which weed control might be achieved in a farm drainage ditch. Considerable expense is incurred on mechanical and chemical methods of weed control in drainage systems, and it is likely that a successful biological control would be widely used in these waterways.

This paper describes the effects of grass carp on the weed infestation in a drainage ditch. A study was also made of the effects on bottom fauna in the ditch, the results of which will be published later.

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