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STOCKING DENSITY, STRAIN PERFORMANCE, AND FEEDING METHOD EVALUATION OF CAGE REARED RAINBOW TROUT (Salmo gairdneri) IN EASTERN SOUTH DAKOTA

BY

DALE B. ALLEN

A thesis submitted
in partial fulfillment of the requirements
for the degree Master of Science, Major in
Wildlife and Fisheries Sciences
(Fisheries Option)
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1986

STOCKING DENSITY, STRAIN PERFORMANCE, AND FEEDING METHOD EVALUATION OF CAGE REARED RAINBOW TROUT (<u>Salmo gairdneri</u>) IN EASTERN SOUTH DAKOTA

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Charles G. Scalet, Ph.D.
Thesis Adviser

Date

Charles G. Scalet, Ph.D., Head
Wildlife and Fisheries Sciences

Date

ABSTRACT

STOCKING DENSITY, STRAIN PERFORMANCE, AND FEEDING METHOD EVALUATION OF CAGE REARED RAINBOW TROUT (*Salmo gairdneri*) IN EASTERN SOUTH DAKOTA

BY DALE B. ALLEN

Methods for cage rearing rainbow trout (*Salmo gairdneri*) were investigated to assist in the development of a landowner aquaculture program for eastern South Dakota. Rainbow trout when stocked as small fingerlings in the spring did not reach a marketable weight (200 g). The fish did attain a size acceptable to some landowners for personal consumption. Maximum stocking density (fish/m^3) was not determined. Densities greater than those used would have been needed to determine the optimum stocking rate. The use of a deeper culture cage (3 m) was justified in this area due to the high water temperatures that were common.

Growth and survival of three strains of cage reared rainbow trout were compared in a gravel pit environment. The Hildebrand strain performed significantly better ($p \leq 0.01$) than the Kamloops and Growth strains for the variables length, weight, survival, and relative weight. An automatic fish feeder and a demand feeder were developed for use in remote locations with cage culture. The automatic feeder treatment produced larger fish than either the demand feeder or hand feeding treatments. Cage culture of rainbow trout in eastern South Dakota is presently not economical in the type of water bodies investigated due to a short growing season imposed by high lethal water temperatures in late June or early July.

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I wish to thank the land owners, Curtis Nelson and Carl Freyberg, for the use of their ponds. I greatly appreciate the rainbow trout from Larry Ferber, Hatchery Manager at the Cleghorn Springs State Fish Hatchery, and the donation of the Hildebrand strain rainbows from Steve Simpson of Trout Haven Ranch, Buffalo Gap, South Dakota.

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INTRODUCTION

Development of aquaculture in eastern South Dakota could create a new industry or supplement landowner food raising ability. Several studies have addressed rainbow trout (*Salmo gairdneri*) culture in the prairie pothole region of the U.S. and Canada. Most investigations in Canada have been directed toward the use of shallow winterkill ponds where high productivity allows annual fish crops from spring fingerling stockings (Lawler et al. 1974; Ayles et al. 1976). Cage culture was used to raise marketable weight rainbow trout during the ice-free season in Manatoba, Canada (Whitaker and Martin 1974). Hahn (1974) had poor success with cage culture of rainbow trout in North Dakota. Recent study of cage culture in eastern South Dakota ponds has been conducted at South Dakota State University. Vodehnal (1982) stocked rainbow trout in dugouts (small excavated pits) but recorded low survival. Good growth and survival of caged trout were reported by Roell (1983) in dugouts. Stocking density and feeding rates were investigated for dugouts by Schuler (1984).

Cage culture methods have been researched in North America in the past two decades. Schmittou (1969) stated that the advantages of suspended cages are; cage culture may be practiced in many types of water bodies such as lakes, reservoirs, farm ponds, mining pits, and estuaries; cages allow a combination of culture methods to be used in a single water body; cage culture allows for easy and complete harvest of the fish; and cages allow easy manipulation of fish to meet market demands, i.e., fish of many sizes can be kept separate and available.

Several possible disadvantages of the cage culture method are; damage to the fish due to rubbing on cages (Collins 1972); increased culture costs associated with cage construction and upkeep (Whitaker and Martin 1974); vandalism and poor feed conversion due to food washing out of the cage (Tatum 1973); and loss of fish from cages due to holes caused by mammals (Sawchyn 1984).

The growth rates and high survival of rainbow trout in dugouts demonstrated by Roell (1983) and Schuler (1984) indicated that cage culture in eastern South Dakota may have potential. In an effort to increase the probability of success, larger and deeper waters were sought which would possibly eliminate the short culture period of approximately 60 days observed in dugouts.

The objectives of this study in 1984 were; 1) to determine if rainbow trout could be cultured to a landowner usable size (200 g) in an eastern South Dakota stock dam, 2) to determine the maximum cage stocking densities of rainbow trout in an eastern South Dakota stock dam, and 3) to determine if a deeper (3m) culture cage would allow for an increased growing season by better use of the total available water column.

The 1985 study objectives were; 1) to determine the practicality of cage rearing rainbow trout in an abandoned gravel pit, 2) to develop and test the efficiency of an automatic and a demand feeder as opposed to hand feeding of caged rainbow trout, and 3) to measure the growth and survival of three strains of rainbow trout (Kamloops, Growth, and Hildebrand) cage reared in a gravel pit.

STUDY AREA

The study areas used in 1984 and 1985 were located in Brookings County in east-central South Dakota. Criteria for pond selection were; short distance from Brookings, minimum water depth of 3.5 m, little or no cattle usage, and landowner permission.

Brookings County lies in the glacially formed Prairie Coteau Highland area between the Minnesota-Red River Lowland on the east and the James River Lowland to the west. The climate is typical of a cool moist prairie area (Westin and Malo 1978). The mean annual temperature is 13.2 C with a mean annual yearly rainfall of 54.9 cm (Westin 1959).

1984 study area

The stock dam used in 1984 was located 21 km S.E. (T109N, R49W, section 35, N.E. quarter) of Brookings (Figure 1). The pond surface area was 0.6 ha with approximately 0.3 ha having a depth > 1 m. Several fish species were present including the largemouth bass (*Micropterus salmoides*), black bullhead (*Ictalurus melas*), and common carp (*Cyprinus carpio*). The stock dam was located at the upper end of a 64 ha pasture. Approximately 60 cattle used the pasture, but the stock dam received light cattle usage because other watering sites were available. The majority of the pond watershed was outside of the pasture and was planted in corn.

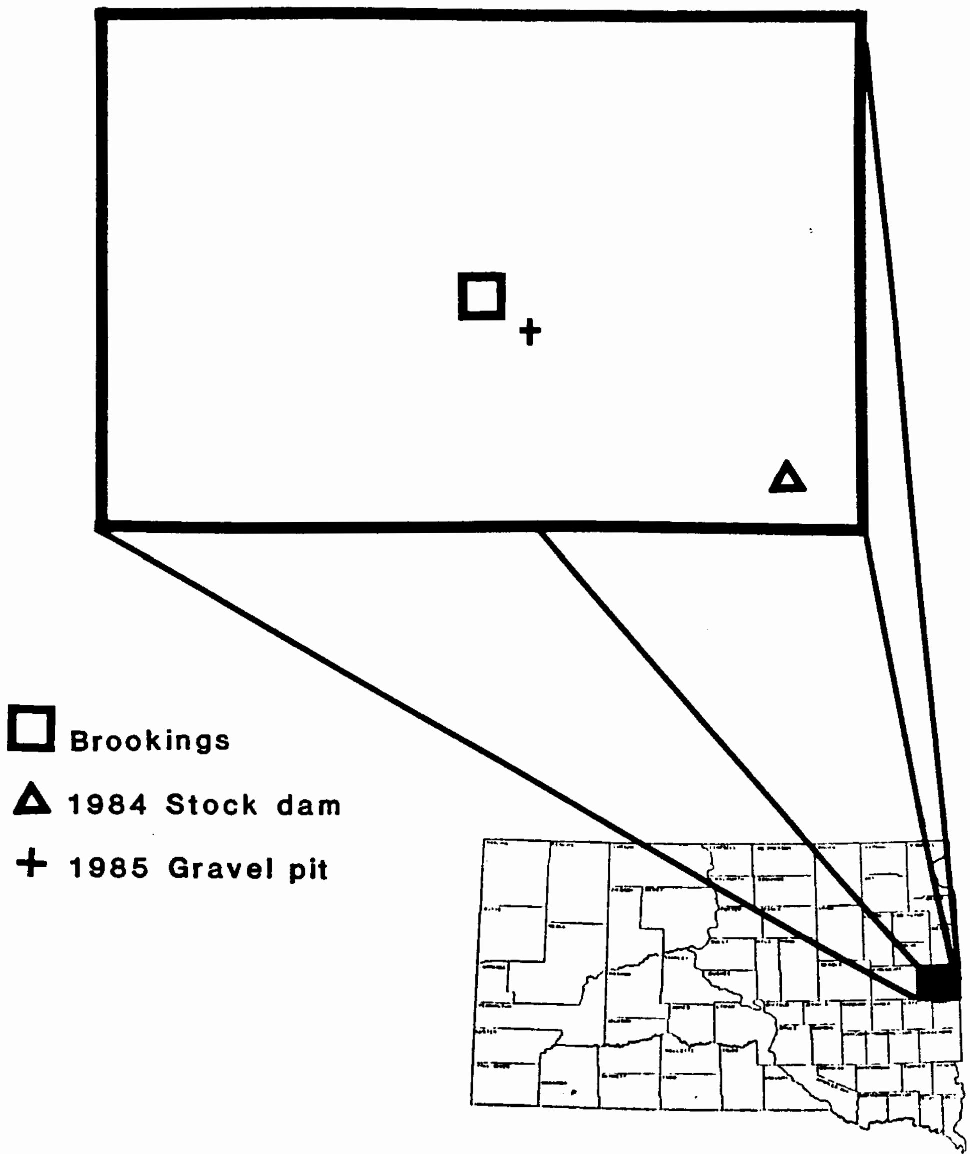

Figure 1. Location of the 1984 and 1985 study areas for cage culture of rainbow trout (Salmo gairdneri) in eastern South Dakota.

1985 study area

An abandoned gravel pit located 5 km S.E. (T110N, R49W, section 32, N.W. quarter) of Brookings was selected for the 1985 experiments (Figure 1). Gravel mining took place from 1966 until 1974. The L-shaped gravel pit was 3 ha in surface area with approximately 80% of the water 4 to 6 m in depth. Several fish species were present in the gravel pit including largemouth bass (Micropterus salmoides), walleye (Stizostedion vitreum vitreum), and northern pike (Esox lucius). There was no cattle usage of the pit.

METHODS AND MATERIALS

1984 Fish density experiment

A randomized complete block experimental design with four treatments and four replications each was used in the 1984 fish density experiment. The treatments were four rainbow trout stocking rates of 60, 80, 100, 120 fish/m^3 in culture cages. This rate resulted in 90, 120, 150, 180 fish in each 1.5 m^3 cage, respectively. Treatments were randomized within each replicate (Figure 2).

Culture cages were constructed of a 1.0 x 0.5 x 3.0 m frame of 38.0 mm^2 pine and covered with 12.7 mm extruded plastic Vexar mesh. An inner mesh of 3.2 mm Vexar, 30.0 cm wide was attached internally in the uppermost part of the cage to form a feeding ring. Removable lids, 1.0 x 0.5 m, of 1.5 cm plywood were constructed with a centered feeding hole 25.0 x 25.0 cm covered with 12.7 mm plastic mesh. Two styrofoam blocks 30.0 x 30.0 x 60.0 cm were attached for floatation at

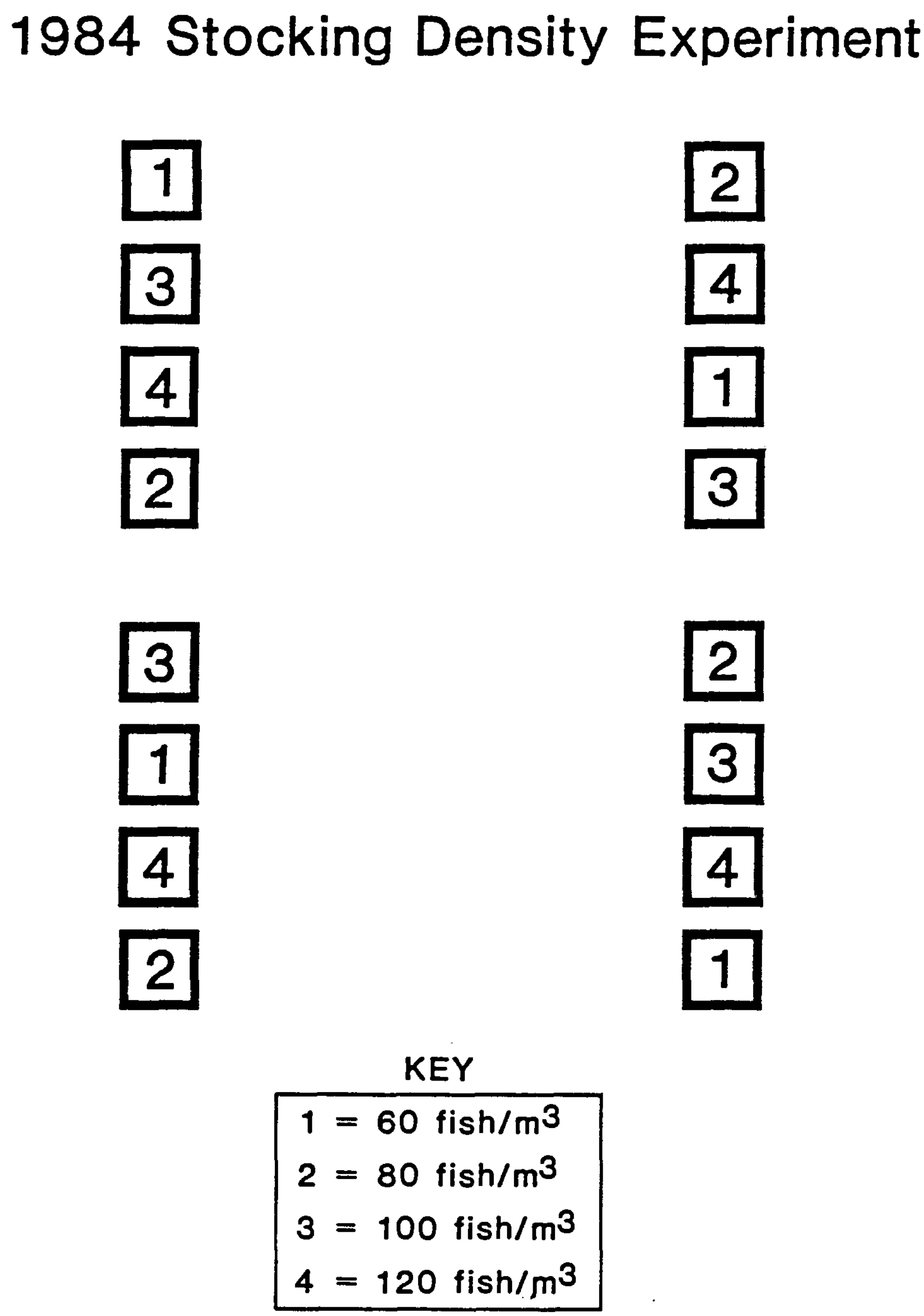

Figure 2. Diagram of experimental design of cage culture of rainbow trout (Salmo gairdneri) study in eastern South Dakota in 1984.

the top on the short axis of the cage (Figure 3). Two concrete blocks were attached on the short axis at the bottom of the cage to ballast the floatation of the wooden cage frame.

The fish cages were placed in two rows facing north to south in the stock pond. Distance between cages was 1.0 m, with 2.0 m space between the replicate blocks. The two rows were placed 3.0 m apart (Figure 2). The cages were anchored with concrete blocks and rope.

Rainbow trout from Cleghorn Springs State Fish Hatchery in Rapid City, South Dakota were stocked into study cages 18 April, 1984. All fish were Growth strain rainbow trout. Fish had been sorted at the hatchery to a mean size of 134.0 mm total length (TL) and 24.8 g (SD 3.02) mean weight. Stocked cages were inspected for fish mortalities by using SCUBA on 3 May; any dead fish were replaced.

Fish were fed a 4.0% body weight per day (bwt/d) ration of floating Purina Trout Chow, containing no less than 37.5% protein, seven days a week in the early evening. On day 35 the food ration was increased to 4.5% bwt/d and remained at that level for the duration of the experiment. Fish sampled on day 34 exhibited a large variation in size and it was felt that an increase in ration percentage might allow more food to be taken by the smaller fish. Feeding began the second day after confinement. A daily weight increase of 1.0 g/day/fish was used (Roell 1983; Schuler 1984) to adjust the daily feeding ration. Any floating food that remained indicated that the ration had been excessive.

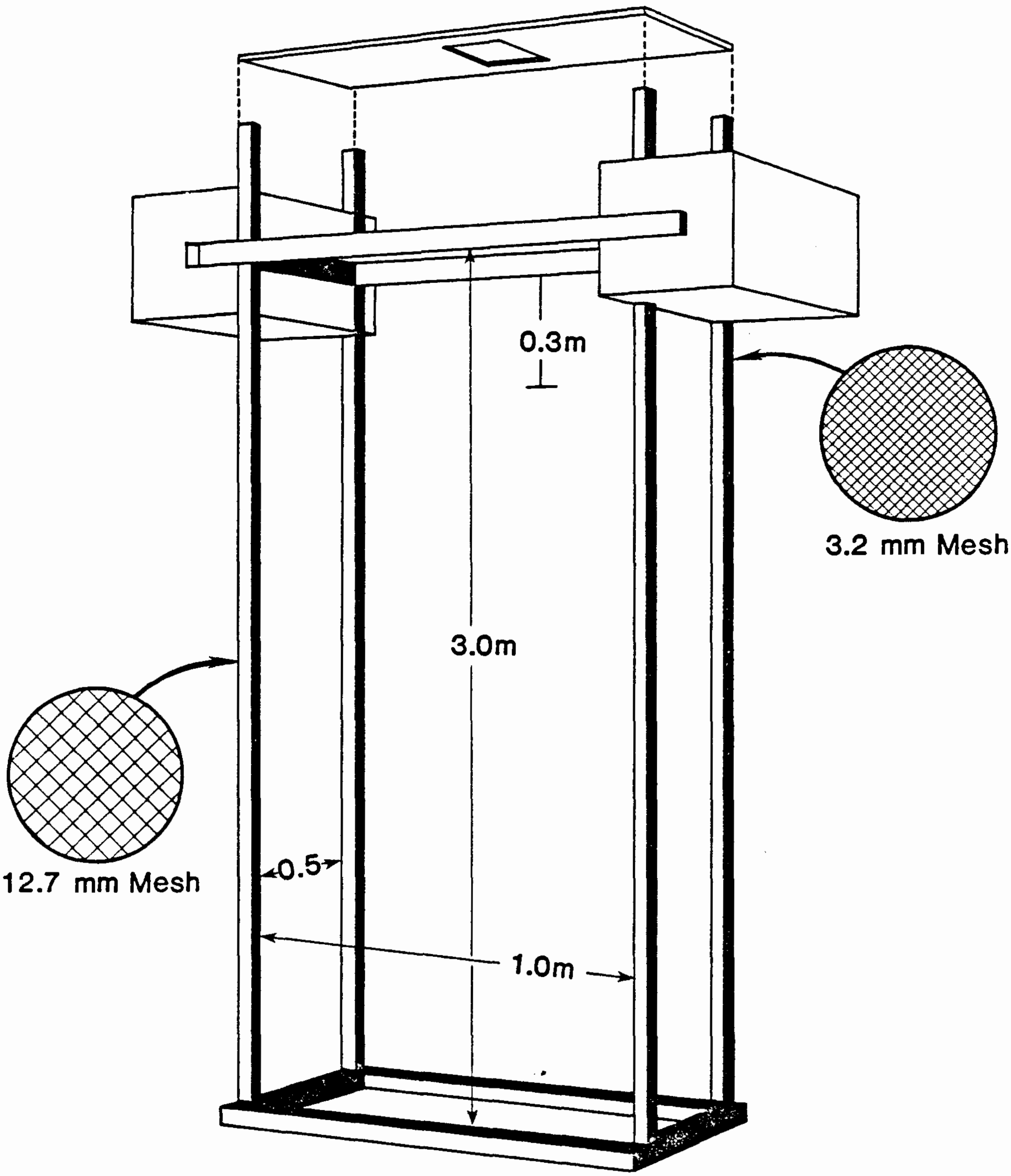

Figure 3. Cage design used for culturing rainbow trout (Salmo gairdneri) in eastern South Dakota in 1984 and 1985.

The experiment was terminated on 26 June, 1984 when surface water temperature was 27.0 C and dissolved oxygen at 2.0 m was 3.1 mg/l. Fish had reduced their feeding two days earlier. All fish were removed, iced and transported to the laboratory for measurement. All fish were measured to the nearest mm TL and to nearest g wet weight.

Water chemistry measurements were taken weekly at a central location within the cage area. Temperature measurements were taken at the surface, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0 m, and bottom using a Yellow Springs Model 33 S-C-T meter. Dissolved oxygen measurements were taken at the same depths as temperature. The Azide Modification of the Winkler method (APHA 1971), utilizing Hach powder pillow reagents, was used to determine dissolved oxygen. Water samples for dissolved oxygen were collected with a 2.2 L PVC Kemmerer water bottle. Surface water pH was measured with a Hach Wide Range pH Color Analizer. Secchi disk visibilities were also recorded.

Analysis of variance was used to test for significance between treatments (stocking density) on the variables length, weight, relative weight (Wr), and food conversion (SAS 1982a; 1982b). Fish survival between treatments was tested by chi-square procedures (Steel and Torrie 1980). The $p \leq 0.05$ and $p \leq 0.01$ levels of probability were used as the significance points. The Waller-Duncan _k_-ratio _t_-test was used to differentiate among significant treatments (Steel and Torrie 1980).

Relative weight (Wr) which compares an actual weight (W) to a standard weight (Ws) was used as an index of condition. Wr values were calculated by the following equation:

$$Wr = (W/Ws) \times 100$$ (Wege and Anderson 1978)

where Wr = relative weight as an index of condition,

W = actual weight of fish in grams, and

Ws = standard weight corresponding to the length of the fish.

The following length-weight equation was used to calculate Ws values

$$\text{Log } Ws = -5.194 + 3.098 \log L$$ (Weithman, personal communication in Anderson 1980).

where L = total length of the fish in mm.

This length-weight equation accounts for changes in body shape as a fish increases in length.

<u>1985 Strain performance evaluation</u>

A randomized complete block experimental design with three strains of rainbow trout as treatments and five replications each was tested by cage culture techniques. Treatments were randomized within each block. A stocking rate of 50 fish/m^3 in 1.5 m^3 cages was used. The rainbow trout were Growth and Kamloops strains from Cleghorn Springs State Fish Hatchery and Hildebrand strain from Trout Haven Ranch in Buffalo Gap, South Dakota. Culture cages from the 1984 season were used; the 3.2 mm Vexar plastic mesh feeding ring was removed. Cages were arranged in one line, in five blocks of three treatments each. The cages were placed 2.0 m apart and the blocks were 3.0 m apart. The cage row started approximately 50.0 m from the eastern shoreline and continued due west (Figure 4).

Fish were sorted into a mean TL length group at Cleghorn Hatchery after sampling of fish lots determined the most abundant 2.0 cm size group. Fish were anesthetized with tricane methane sulfonate and quinaldine, which reduced stress on the fish while measurements were taken. The mean TL were 107.3 mm (SD 5.5) and 105.4 mm (SD 5.7) for the Growth and Kamloops strains, respectively. Mean weight for the Growth strain was 14.6 g (SD 2.2) and for the Kamloops strain was 14.6 g (SD 2.4). Fish were sorted by a mechanical slot grader at Trout Haven Ranch. Mean length of the Hildebrand strain was 101.3 mm (SD 7.1) with a 12.2 g (SD 2.8) mean weight. All fish were transported by a state fish transport truck overnight, and stocked into study cages 11 April, 1985. Caged trout were fed a 4.0% bwt/d ration of sinking Glencoe Mills Trout Grower Pellets. The 1.0 mm diameter dry pellets contained at least 41.0% protein and were fed once daily in the evening, seven days a week. The daily feed ration was adjusted by calculating daily growth rates by weighing at least 15 fish of each strain biweekly. Sampled fish were weighed in lots which did not allow individual measurements or variances.

Water chemistries were taken once weekly by methods described in the 1984 experiment. Dissolved oxygen and temperature measurements were taken at the surface, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0 m, and bottom.

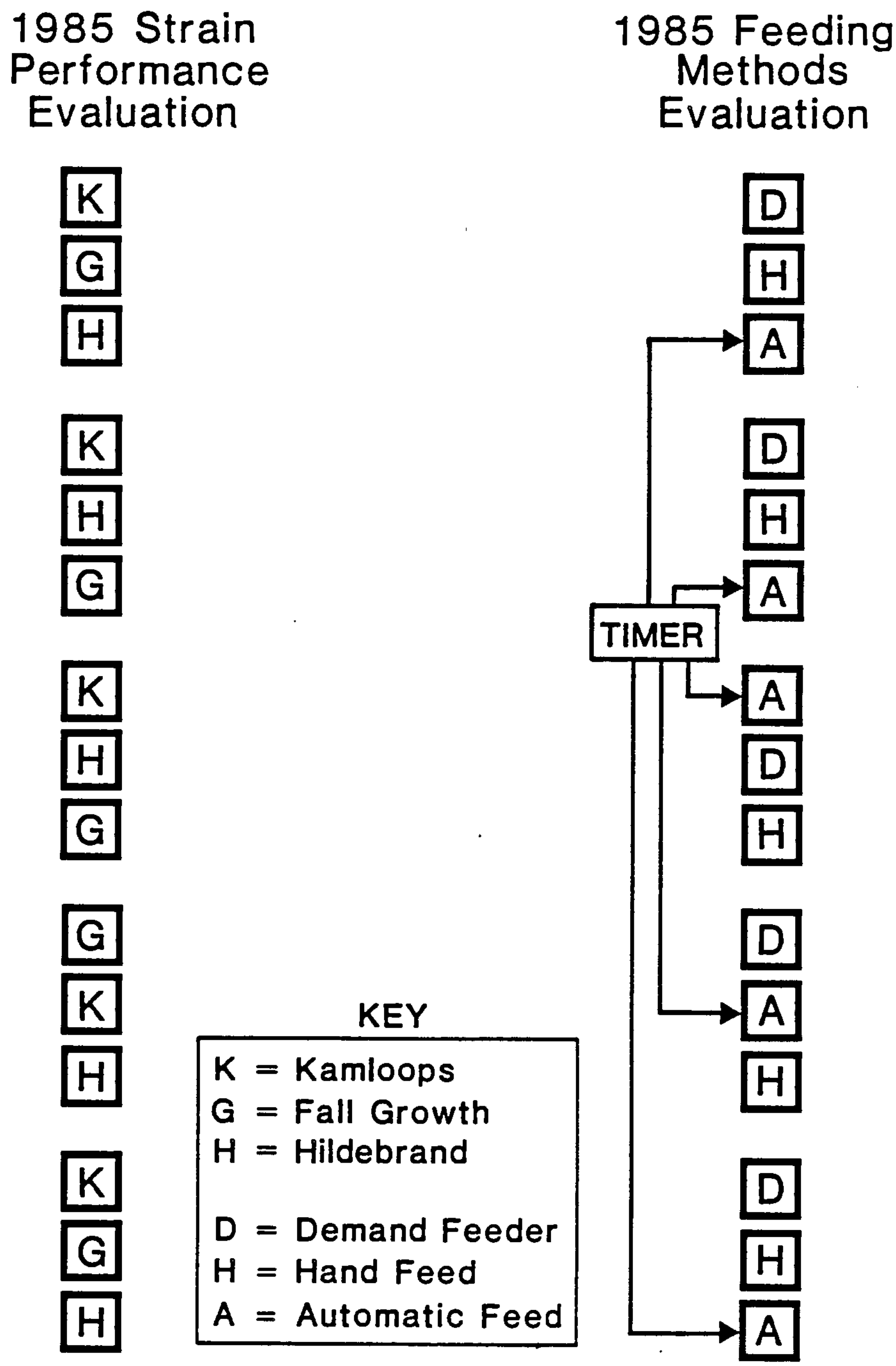

Figure 4. Diagram of experimental design of cage culture of rainbow trout (Salmo gairdneri) study in eastern South Dakota in 1985.

Statistical analysis procedures were employed as in the 1984 analysis. A length-weight regression was calculated to estimate missing weight data due to unreliable weights from recently deceased fish. It was felt that length data from fish that died just proceeding harvest would be reliable to estimate wet weights and thus be used in the analysis. The regression equation for each of the trout strains and number of weights estimated are listed below with their r^2 values:

Kamloops weight = -121.859 + 1.082(length) $n = 34$, $r^2 = .92$,

Growth weight = -127.974 + 1.111(length) $n = 107$, $r^2 = .90$,

Hildebrand weight = -140.229 + 1.204(length) $n = 37$, $r^2 = .92$.

Chi-square tests for independent comparisons were used for significant differences in survival (Steel and Torrie 1980).

1985 Feeding methods evaluation

A randomized complete block experimental design with three treatments and five replications per treatment was conducted using cage culture methods. The treatments were; demand feeders that were activated by a fish moving a rod (trigger), hand feeding at a rate of 4.0% bwt/d, and automatic timed volumetric feeders that dispensed food at timed intervals during daylight hours at a 4.0% bwt/d ration.

The demand feeders were constructed using a piece of 32.0 cm PVC sewer pipe 16.0 cm in diameter. A 16.0 cm plastic funnel was attached internally at the bottom. A 5.0 cm plexiglass disk 2.0 mm thick was suspended directly below the funnel opening and was constructed to allow adjustment for feed amount regulation (Figure 5). The rod (trigger) was 0.5 mm piano wire which extended 0.7 m into the culture cage. The feeder could contain 2.0 kg of fish food pellets.

The automatic feeders were a volumetric dumping device activated with a 12V DC solenoid powered by a 12V DC automobile storage battery and regulated by a programable timer. The feeder body was constructed of 9.0 x 4.0 cm redwood lumber (Figure 6 and 7). The feed hopper was a 50.0 cm length of thin wall PVC tubing 10.5 cm in diameter attached above the dispensing mechanism. A plastic tube 25.4 mm diameter connected the feed hopper to the dispenser (Figure 7a). The feed dispenser was constructed of five 8.0 cm diameter disks of 6.0 mm thick plexiglass bolted together (Figure 7b). The center three disks had a 108^{o} section removed and thus formed a volume that contained 15.0 g of feed pellets. A Guardian Electronics T12X19-1-12V DC solenoid rotated the disk 50^{o} from resting causing the feed pellets to be dumped. The feed dispenser closed off the feed hopper tube when the feed dispenser was in the dumping position. A spring returned the feed dispenser to its resting position after current was shut off to the solenoid. A plastic window on the feeder sidecover allowed visual inspection of the dispenser to identify any malfunction.

The battery and programmable timer were mounted in a plastic cooler that floated alongside a culture cage. A Lehman H Model number 2HH612 timer was used. It allowed programmed on and off operation at any time interval in a 24 hr period. The timer was set to allow the solenoids to remain activated for 5 seconds thus assuring all feed

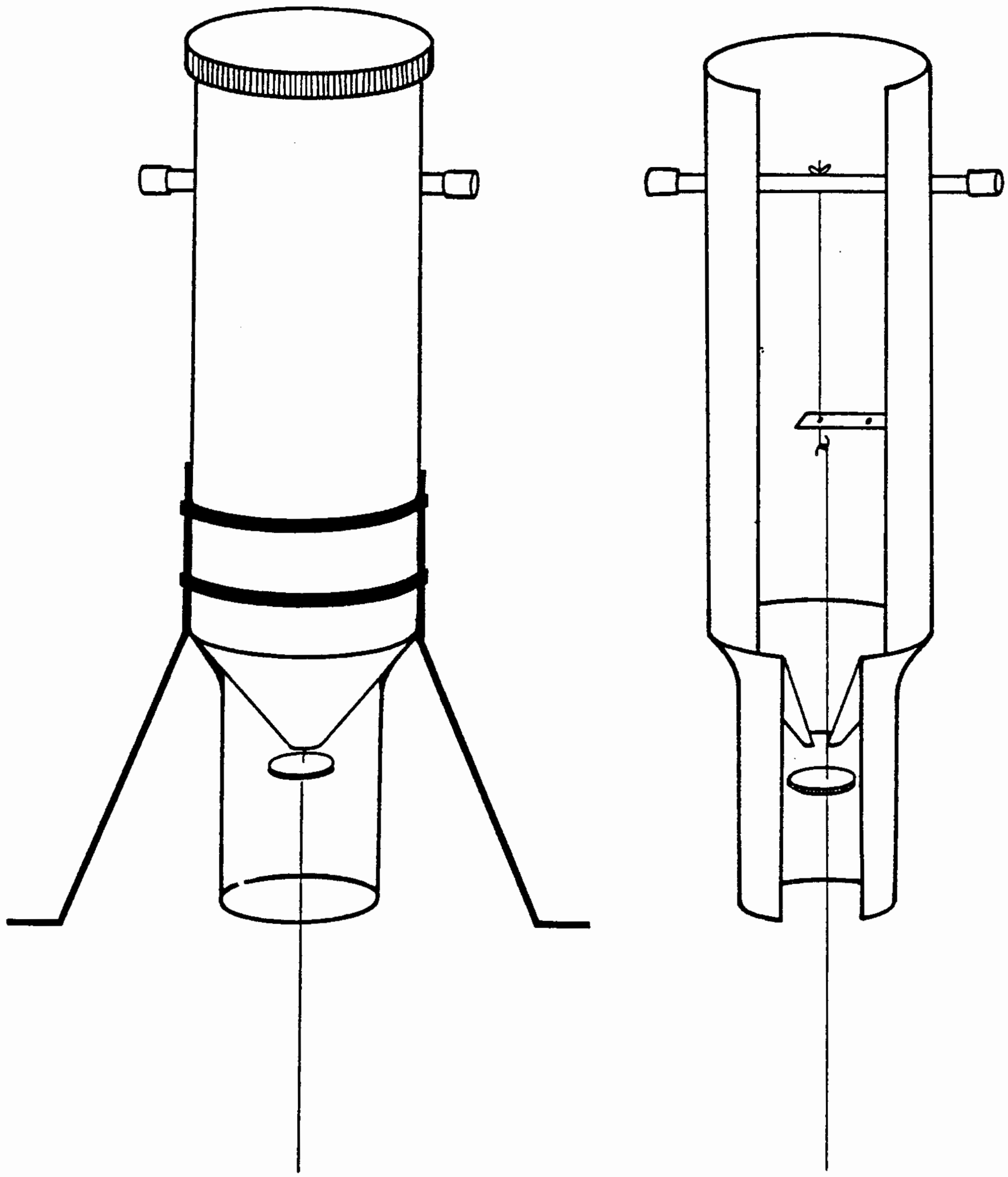

Figure 5. Diagram of demand feeder used for cage culture of rainbow trout (*Salmo gairdneri*) in eastern South Dakota in 1985.

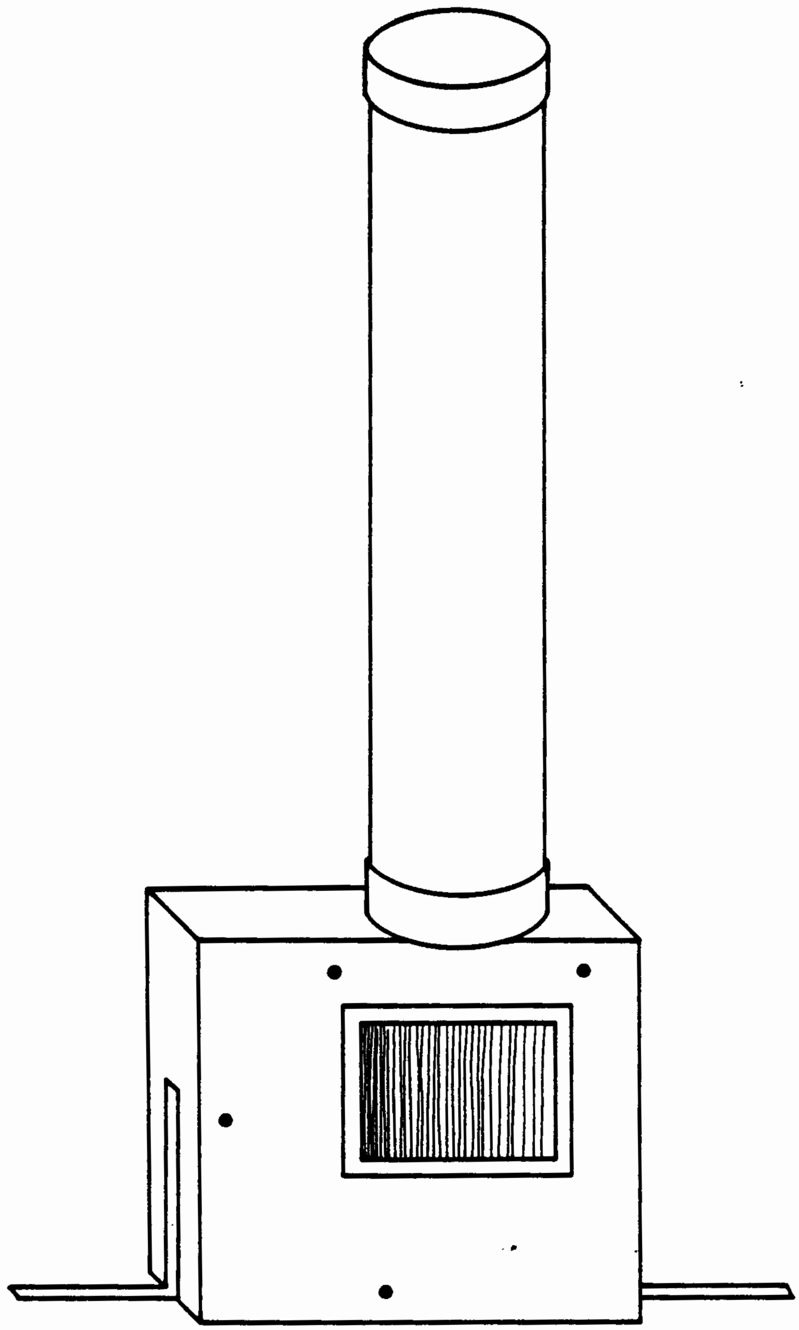

Figure 6. Drawing of the automatic feeders used in the 1985 cage culture study of rainbow trout (Salmo gairdneri) in eastern South Dakota.

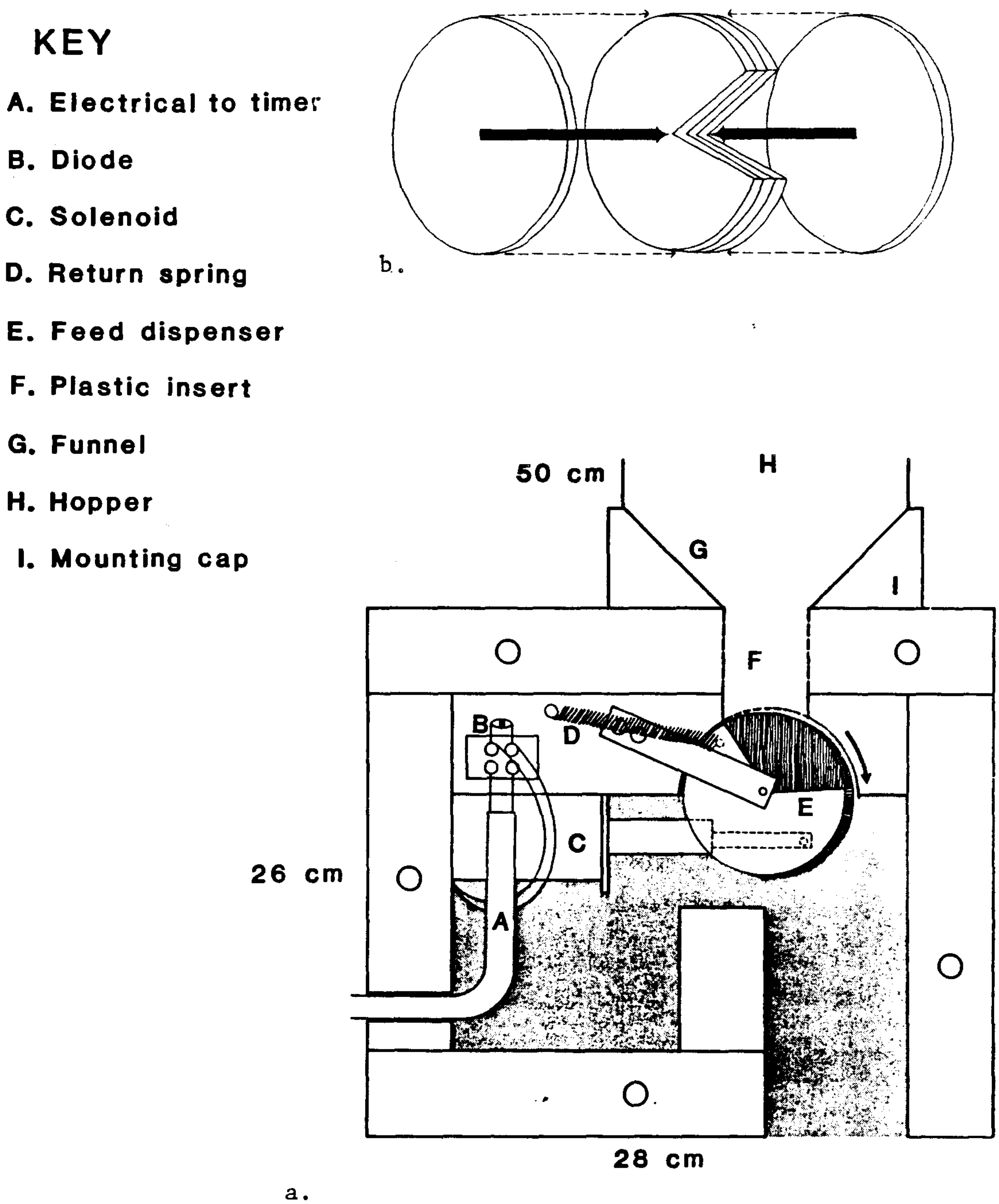

Figure 7. a. Schematic drawing of automatic feeder used in the 1985 cage culture study of rainbow trout (Salmo gairdneri) in eastern South Dakota. b. Enlargement of feed dispenser, showing construction.

pellets were dumped. A Midtex 20 amp relay was installed in the circuit to enable the timer to withstand the current load from the solenoids. The five feeders were run in parallel circuits using solid copper three strand 12 guage insulated wire (Figure 4).

All fish used were Growth strain rainbow trout that were selected and stocked as described for the strain performance test. The fish were stocked at $50/m^3$ in cages for a total of 75 fish/cage. Cages were constructed as described in the 1984 experiment. Cages were placed approximately 30.0 m south of the cages for the strain test and anchored as before (Figure 4).

All fish were fed 1.0 mm sinking Glencoe Mills Trout Grower Pellets seven days a week. The demand feeders were inspected daily and refilled when necessary. Hand fed fish were given a 4.0% bwt/d ration in the late afternoon or early evening. The automatic timed feeder treatment had 15.0 g of feed pellets dispensed at intervals grouped in the morning and evening to equal a 4.0% bwt/d ration. The ration for the automatic and hand fed fish treatments was calculated daily by using the daily growth rate obtained from sampling fish biweekly.

Water quality data were collected weekly as described for the strains experiment. Statistical analysis was the same as desribed in the 1984 experiment. Length-weight regression equations were calculated to estimate wet weights of recently deceased trout that were used in the analysis. The equations and number of weights estimated and r^2 values are listed below for the three treatments:

Demand weight = −138.476 + 1.205(length) $n = 10$, $r^2 = .90$,

Hand weight = −107.632 + 1.015(length) $n = 6$, $r^2 = .91$,

Automatic weight = −134.988 + 1.187(length) $n = 6$, $r^2 = .90$.

RESULTS AND DISCUSSION

1984 density experiment

Production

There were no significant differences ($p>0.05$) for the variables length, weight, and Wr at the four stocking densities of 60, 80, 100, 120 fish/m^3 (Tables 1-4). Chi-square analysis showed significant differences ($p\leq0.05$) in survival between treatments (Tables 1 and 5).

Four authors tested fish stocking densities smaller or overlapping with this study. Hahn (1974) had stocking densities of 50, 100, 150, 200, 250, and 300 fish/m^3 and found differences in harvest weight, average weight gain/day, and survival that were inversely related to stocking density. Although not investigating maximum cage stocking density Roell (1983) reported higher final weights, greater average weight gain/day, and approximately equal survival to this study at densities of 35 fish/m^3. Schuler (1984) had stocking densities of 35, 52, and 70 fish/m^3 and found better growth and approximately equal survival to this study at 35 and 52 fish/m^3. In one dugout (70 fish/m^3) fish growth and survival were lower than this study, but the author attributed the poor growth to water turbidity. At densities from 69 fish/m^3 to 106 fish/m^3 Sawchyn (1984)

Table 1. Growth, survival, and production results from cage culture of rainbow trout (Salmo gairdneri) in an eastern South Dakota stock dam between 18 April and 26 June, 1984.

	Stocking Density (Number of fish/m^3 in 1.5 m^3 cages)			
	60	80	100	120
Number of fish				
Initial	360	480	600	720
Final	352	478	591	700
Percent survival	97.8	99.6	98.5	97.2
Mean length (TL mm)				
Initial	134.0	134.0	134.0	134.0
Final	178.0 (SD 19.9)	178.2 (SD 20.1)	177.4 (SD 18.4)	175.3 (SD 19.6)
Mean Weight (g)				
Initial	24.8	24.8	24.8	24.8
Final	73.9 (SD 23.5)	74.0 (SD 24.8)	72.5 (SD 22.4)	70.5 (SD 23.9)
Food conversion	2.9	2.8	2.9	3.1
Relative weight (Wr)	118.3	117.9	117.9	117.6
Mean individual weight gain/day (g)[a]	0.73	0.73	0.71	0.68
Mean biomass gain (kg/m^3)	3.97	5.40	6.53	7.48

[a]Based on number of days fed (67 out of 70 days held).

Table 2. Analysis of variance for dependent variable length of rainbow trout (Salmo gairdneri) cage cultured in an eastern South Dakota stock dam between 11 April and 26 June, 1984.

Source of Variation	Degrees of Freedom	Mean Square	F
Stocking rate (SR)	3	967.24	0.53 NS*
Rep	3	2,512.30	1.39
SR X Rep	9	1,808.44	
Residual	2,015	368.98	

*Not significant at the 0.05 level of probability.

Table 3. Analysis of variance for dependent variable weight of rainbow trout (Salmo gairdneri) cage cultured in an eastern South Dakota stock dam between 18 April and 26 June, 1984.

Source of Variation	Degrees of Freedom	Mean Square	F
Stocking rate (SR)	3	1,481.75	0.51 NS*
Rep	3	3,525.54	1.21
SR X Rep	9	2,914.52	
Residual	2,105	544.77	

*Not significant at the 0.05 level of probability.

Table 4. Analysis of variance for dependent variable relative weight (Wr) of rainbow trout (Salmo gairdneri) cage cultured in an eastern South Dakota stock dam between 18 April and 26 June, 1984.

Source of Variation	Degrees of Freedom	Mean Square	F
Stocking rate (SR)	3	30.55	0.02 NS*
Rep	3	1,000.15	0.83
SR X Rep	9	1,204.04	
Residual	2,105	128.48	

*Not significant at the 0.05 level of probability.

Table 5. Chi-square analysis for dependent variable survival of rainbow trout (*Salmo gairdneri*) cage cultured in an eastern South Dakota stock dam between 18 April and 26 June, 1984.

Stocking Rate	Alive Observed	Dead Observed
60 fish/m^3	352	8
80 fish/m^3	478	2
100 fish/m^3	591	9
120 fish/m^3	700	20

$$\chi^2 = 9.73^* \text{ with 3 df}$$

*Significant at the 0.05 level of probability.

Chi-square independent comparisons among the treatments (fish/m^3).

60	80	100	120

Underlined treatments are not significantly different.

reported final mean weights to 290.1 g with 1.6 g/fish/day average weight gain in cage cultured trout in Saskatchewan.

Many studies have investigated higher rearing densities than were used for this study. Collins (1972) found no differences in growth or survival between 260 and 493 fish/m^3 in winter cage reared trout in Arkansas. Differences were reported for final weights of trout cultured at 183 and 523 fish/m^3 in winter culture (Kilambi et al. 1977). Average weight gain/day decreased as density increased, but no difference in survival was reported (Kilambi et al. 1977). At final rearing densities of 273 and 419 fish/m^3, Whitaker and Martin (1974) recorded higher weights and daily weight gains than in this study. Survival was lower (54%) than this investigation and was attributed to high water temperatures and an outbreak of _Columnaris_. Trzebiatowski et al. (1981) reported an inverse relationship between harvest weight and daily weight gain with stocking densities to 900 fish/m^3. No relationship was discovered between fish density and survival (Trzebiatowski et al. 1981).

Survival at the highest stocking density was significantly lower ($p \leq 0.05$) than in the treatments 60, 80, and 100 fish/m^3. Only 20 fish died in the 120 fish/m^3 treatment during the experiment. The highest stocking density had lower final mean lengths, mean weight, and mean individual weight gain/day (Table 1) which could indicate a slight density effect. Since only the variable survival was different among treatments there was not enough evidence to conclude that a upper stocking density had been reached.

There were no significant ($p>0.05$) differences in Wr between stocking density treatments. Significant Wr differences ($p\leq0.05$) were found by Roell (1983) and Schuler (1984) between fed and non-fed trout, but not between different ration levels. Wr means from this study ranged from 117.6 to 118.3 and were higher than those reported by Roell (1983) and Schuler (1984). The standard weight (Ws) used in the Wr equation compensates for body changes as a fish grows, Wr reduces the variability that was inherent in other condition indexes (Wege and Anderson 1978). The high Wr values obtained in this study indicated that food was not limiting and confirmed the plump appearance of the fish at harvest.

A fish density equal to 3,600 trout/ha was used in this study. A stocking density of 8,650 trout/ha was used by Roell (1983) based on a study by Halverson et al. (1980) using open water ponds. Roell (1983) stated that cage stocking densities in dugouts could be doubled. Schuler (1984) increased the stocking rate to 17,500 trout/ha. No density effects or reductions in growth due to oxygen depletion or wastes were reported by either author. The density choosen for this study was a numerical progression of previous densities used by Schuler (1984). Higher cage densities and the resulting lower pond fish density were used in this study to reduce any effect of pond carrying capacity, i.e., a cage density effect would become apparent.

Food conversion

Food conversion between treatments was not significantly ($p>0.05$) different (Table 6). Treatment food conversion efficiencies were from 2.8 to 3.1 (Table 1). A general increase in food conversion values with increasing fish density is revealed in the literature. Hahn (1974) and Kilambi et al. (1977) found decreasing food conversion efficiences with increasing densities. Collins (1972) reported slightly decreased food conversion efficiency for the highest fish density tested. Food conversion efficiency was higher in 90 than 106 fish/m^3 densities in dugout cage culture (Sawchyn 1984).

The 4.0% bwt/d ration used in this study was from Roell (1983) assessment that a cage culture ration for eastern South Dakota should be between 3.0 and 4.0% bwt/d. By using a 4.0% bwt/d ration enough feed would be presented to the fish for maximum growth. A food conversion efficiency of 1.8 while using a 4.0% bwt/d ration was reported by Roell (1983). Schuler (1984) reported food conversion rates of 1.8, 1.6, and 1.5 at densities of 35, 52, and 70 fish/m^3 fed a 3.0% bwt/d ration. His 5.0% bwt/d ration resulted in food conversions of 3.2, 2.5, and 2.6 at the three stocking densities examined, these food conversion efficiences were comparable to this study. The 4.5% bwt/d ration used during the second half of the study probably contributed to the low food conversions found in this study. It is difficult to estimate the correct ration to administer because of the interrelating factors of fish size, density, water temperature, and number of daily feedings. Buck et al. (1972) reported varying

Table 6. Analysis of variance for dependent variable food conversion of rainbow trout (*Salmo gairdneri*) cage cultured in an eastern South Dakota stock dam between 18 April and 26 June, 1984.

Source of Variation	Degrees of Freedom	Mean Square	F
Stocking rate	3	.077	0.794 NS*
Rep	3	.125	
Residual	9	.097	

*Not significant at the 0.05 level of probability.

food conversion rates dependent on the average temperature during the sampling period. He found better food conversion values during periods of 15.0 C or less water temperatures. Better food conversion and growth rate were reported by Sawchyn (1985) in dugouts when water temperatures were over 20.0 C. Possibly better food conversion would have been realized if feeding had been divided between early morning and early evening. Trzebiatowski et al. (1981) fed five to six times daily and reported food conversion efficiences of 1.5 to 1.9 at densities to 900 fish/m^3.

Feeding behavior

Fish feeding behavior was observed daily. Approximately 25% of the floating ration sank immediatly. Fish were attracted to the sinking pellets which brought the fish to the surface for the remaining ration. Any food remaining in the cages the next day was a visual indicator of food pellet consumption.

During the first three weeks of cage rearing there was little indication of fish feeding. No surface activity was observed and much feed remained floating until the following day. Water temperatures (Appendix Table 1) were low until the third week of the study when surface temperatures reached 13.5 C.. Water clarity was also low due to algal blooms in April. The lower temperature probably reduced the fishes demand for food and much of the daily food ration remained uneaten. The poor water visability reduced any observations of fish feeding.

During the following four weeks, aggressive surface feeding occured where fish rapidly came to the surface and fed. From the second week in June until harvest there was a general decline in feeding intensity. This was probably due in part to an increase in water temperature and a decrease in dissolved oxygen partially caused by a lengthy rainy period. Harvest of all fish took place on 26 June, after 70 days, when it was felt that temperature and dissolved oxygen concentrations had become critical for survival of the rainbow trout (Appendix Table 1).

Water quality

Temperature, dissolved oxygen, pH, and secchi disk visibility measurements from 18 April to 26 June, 1984 are recorded in Appendix Table 1. Temperature and dissolved oxygen were not limiting to trout survival until about 25 June when both temperature and dissolved oxygen began to reach critical levels. Cherry et al. (1977) found 26.0 C to be lethal for rainbow trout in acclimatization trials. Data from 26 June (Appendix Table 1) show temperatures as lethal for the upper 1.0 m of the culture cage. Dissolved oxygen above 5.0 mg/l is generally considered adequate for rainbow trout growth and survival (Piper et al. 1982). During the last week of the culture period dissolved oxygen was below 5.0 mg/l; this likely stressed the fish.

The high water temperatures and low dissolved oxygen levels were probably due to the high turbidity in study pond caused by rainwater runoff. The turbid water increased absorbance of solar radiation. The turbidity also caused a decline in oxygen production due to lower light penetration reducing photosynthesis. This rainy period most likely shortened the culture period by approximately two weeks.

Fish density conclusion

A maximum cage stocking density (fish/m^3) was not determined. The possibility of fish respiration causing dissolved oxygen problems was one concern which led to the use of the fish densities utilized. Roell (1983) stated that there was no difference in dissolved oxygen measured within the cage culture area versus outside of the cage area. Fish respiration was found to be a minor component of night-time dissolved oxygen budgets for rainbow trout ponds in Alabama (Halverson et al. 1980). A cage stocking density of three to four times greater than the density used could have realized more information.

1985 Strain performance evaluation

Production

Significant differences ($p \leq 0.01$) in length, weight, and Wr (Tables 7-10) were determined by analysis of variance. Chi-square analysis indicated significant differences ($p \leq 0.01$) in survival among the treatment trout strains (Table 11). Length was greatest for the Hildebrand strain followed by the Kamloops and Growth strains, respectively (Table 7). The highest mean weight, mean individual weight gain/day, and biomass production was recorded for Hildebrand

Table 7. Growth, survival, and production results from three strains of rainbow trout (Salmo gairdneri) cage cultured in an eastern South Dakota gravel pit between 11 April and 10 July, 1985.

	Rainbow Trout Strains		
	Kamloops	Growth	Hildebrand
Number of fish			
Initial	375	375	375
Final	340	190	357
Percent survival	90.7	50.7	95.2
Mean length (TL mm)			
Initial	105.4	107.3	101.3
Final	175.2 (SD 17.8)	170.8 (SD 16.0)	179.9 (SD 16.1)
Mean weight (g)			
Initial	14.6	14.6	12.2
Final	67.7 (SD 20.1)	61.8 (SD 18.3)	76.4 (SD 20.1)
Food conversion	2.9	21.0	2.4
Relative weight (Wr)	114.7	112.8	120.5
Mean individual weight gain/day[a]	0.60	0.54	0.73
Mean biomass gain (kg/m^3)	2.34	0.83	3.03

[a]Based on number of days fed (88 out of 91 days held).

Table 8. Analysis of variance for dependent variable length of three strains of rainbow trout (Salmo giardneri) cage cultured in an eastern South Dakota gravel pit between 11 April and 10 July, 1985.

Source of Variation	Degrees of Freedom	Mean Square	F
Trout Strain (STR)	2	4,728.60	15.06**
Rep	4	265.21	0.84
STR X Rep	8	314.06	
Residual	872	281.26	

**Significant at the 0.01 level of probability.

Waller-Duncan k-ratio t-Test for the significant variable length.

Treatment (Trout Strains)	Mean (TL mm)	
Hildebrand	179.94	A*
Kamloops	175.16	B
Growth	170.80	C

*Strains with different letter are significantly different (k-ratio = 500).

Table 9. Analysis of variance for dependent variable weight of three strains of rainbow trout (*Salmo gairdneri*) cage cultured in an eastern South Dakota gravel pit between 11 April and 10 July, 1985.

Source of Variation	Degrees of Freedom	Mean Square	F
Trout Strain (STR)	2	13,386.17	38.69**
Rep	4	485.58	1.4
STR X Rep	8	345.95	
Residual	872	389.65	

**Significant at the 0.01 level of probability.

Waller-Duncan *k*-ratio *t*-Test for the significant variable weight.

Treatment (Trout Strains)	Mean (g)	
Hildebrand	76.42	A*
Kamloops	67.74	B
Growth	61.77	C

*Strains with different letters are significantly different (*k*-ratio = 500).

Table 10. Analysis of variance for dependent variable relative weight of three strains of rainbow trout (*Salmo gairdneri*) cage cultured in an eastern South Dakota gravel pit between 11 April and 10 July, 1985.

Source of Variation	Degrees of Freedom	Mean Square	F
Trout Strain (STR)	2	5,211.59	13.77**
Rep	4	711.41	1.88
STR X Rep	8	378.58	
Residual	872	75.01	

**Significant at the 0.01 level of probability.

Waller-Duncan *k*-ratio *t*-Test for the variable relative weight.

Treatment (Trout Strains)	Mean (Wr)	
Hildebrand	120.46	A*
Kamploops	114.72	B
Growth	112.81	C

*Strains with different letters are significantly different (*k*-ratio = 500).

followed by Kamloops and Growth strains, respectively (Table 7). Final mean weight of the Growth strain fish was lower than the 1984 stocking density study results, which was probably due to the 10.0 g smaller initial size used in 1985. Greater final mean weights were found by (Collins 1972; Tatum 1973; Whitaker and Martin 1974; Kilambi et al. 1977; Roell 1983; Sawchyn 1984; Schuler 1984). Hahn (1974) in North Dakota found lower mean weights and lower mean weight gain/day than in this study. Only Hahn (1974), Whitaker and Martin (1974), and Sawchyn (1984) began culture with smaller size trout.

The Hildebrand strain Wr was significantly ($p \leq 0.01$) larger than Kamloops which was also significantly larger than the Growth strain fish (Table 10). The Growth strain Wr values were approximately equal to those found by Roell (1983) for his 2.0% and 4.0% bwt/d ration treatment. Schuler (1984) reported larger Wr means for Growth strain fish stocked at 52 fish/m^3 and lower Wr means at 70 fish/m^3 than found in this study.

Survival

Chi-square analysis found significant differences ($p \leq 0.01$) for survival between the treatment strains (Table 11). There was no difference between Hildebrand and Kamloops strains, but a significant difference existed between the Growth and the other two strains. At final harvest, the Growth strain had 50.7% survival which was lower than any reported in the cage culture literature.

Table 11. Chi-square analysis for dependent variable survival of three strains of rainbow trout (*Salmo gairdneri*) cage cultured in an eastern South Dakota gravel pit between 11 April and 10 July, 1985.

Trout Strains	Alive Observed	Dead Observed
Kamloops	340	35
Growth	190	185
Hildebrand	357	18

$$\chi^2 = 270.07^{**} \text{ with 2 df}$$

**Significant at the 0.01 level of probability.

Chi-square independent comparisons among the treatment means.

$\underline{340 \quad 357}$ 190

Underlined values denote no significant difference.

No fish mortality was observed until 15 June when several dead fish were found in the cages. Until three days before harvest 11 Growth, 7 Kamloops, and 1 Hildebrand strain fish had died. Dead fish did not appear until water temperatures exceeded 20.0 C throughout the culture cages (Appendix Table 2). During 7 and 8 July, 73 Growth, 11 Kamloops, and 6 Hildebrand strain fish were found dead. On those dates surface water temperatures of 27.5 and 25.0 C were recorded, respectively. All fish from the experiment were harvested on 10 July because the feeding methods cage row had to be removed on 9 July to allow access to the strain cage row. Many dead fish were badly decomposed from the high water temperatures and accurate length measurements could not be taken. These fish were thus not used in this analysis.

It appears that the there may be a difference in temperature tolerence between the three strains. Unfortunately all strains were harvested which did not allow complete investigation of that possiblity.

Food conversion

Food conversion efficiency of the three trout strains was not significantly different ($p>0.05$) (Table 12). Food conversion treatment means were from 2.4 to 21.0 (Table 7). Replicate (cage) food conversion values of the Growth strain were from 3.0 to 65.7, 2.6 to 3.3 for Kamloops, and 2.3 to 2.5 for the Hildebrand strain trout.

Table 12. Analysis of variance for dependent variable food conversion of three strains of rainbow trout (*Salmo gairdneri*) cage cultured in an eastern South Dakota gravel pit between 11 April and 10 July, 1985.

Source of Variation	Degrees of Freedom	Mean Square	F
Trout Strain	2	563.30	2.47 NS*
Rep	4	225.35	
Residual	8	227.70	

*Not significant at the 0.05 level of probability.

The higher range in the Growth strain treatment was the result of one replicate having higher survival (88.0%) than the other replicates.

Trout strains

A strain is defined as a fish population that exhibits reproducable physiological, morphological, or cultural performance characteristics that are significantly different from other fish populations (Kincaid 1981). This definition is based on natural selection pressures of a particular environment over time producing uniqueness. The fish strains that were used in this experiment fit this definition.

A strain evaluation should subject all fish to the same culture conditions. This was not complete in this study because the experimental fish were obtained from two hatcheries. The Kamloops and Growth strains from Cleghorn Springs State Fish Hatchery were raised under the same cultural practices, i.e., same feed and raceway densities were used. Water temperature and quality were the same for these two strains. The Hildebrand strain trout from Trout Haven Ranch were raised under different cultural conditions. This strain was raised on different feed and in warmer water than the other two strains. Cage rearing of the strains was identical, but it is impossible to state with complete assurance that all differences in measured variables were due to cage culture and were not influenced by the hatchery environment in early life history.

Kamloops

The Kamloops strain of Cleghorn Hatchery originated from a commercial producer, Trout Lodge, McMillin, Washington (Kincaid 1981). Since introduction, a brood stock has been maintained at the hatchery in Rapid City. Initial hatching for the group of fish used was 1 October, 1984 and the fish were reared in raceways at 11.2 C. The fish were fed a prepared diet for 144 days before they were stocked in the gravel pit.

Growth

The Growth strain trout of Cleghorn Hatchery were obtained from the Fish Genetics Laboratory, Beulah, Wyoming in 1975 (Kincaid 1981). This strain is the result of the 1965 cross between rainbow trout from Manchester, Iowa and Wytheville National Fish Hatchery. Fast growth, through selection on the basis of family mean fish weight at 147 days post-fertilization, was the reason that this strain was developed (Kincaid et al. 1977). The Growth strain is noted for fast growth in the hatchery and excellent food conversion. Initial hatching date was 22 October, 1984 and the fish were reared under the same conditions as the Kamloops strain. These fish were fed a prepared diet for 155 days prior to stocking.

Hildebrand

The Hildebrand strain of Trout Haven Ranch were raised from eggs bought from Mt. Lassen Trout Farm, Red Bluff, California. The strain was originally developed from a cross between Trout Lodge, Kamloops strain and Mt. Shasta strain rainbow trout from Coleman National Fish Hatchery. The last outside eggs were brought in during the early 1960's, so a 20 year isolation has been in effect. Selection has been for; number of eggs/wt., size, and food conversion (Keith Brown, Mt. Lassen Trout Farm, personal communication). Eggs were hatched 3 December, 1984 and reared in earthen ponds at 15.6 C. Fish were fed an artificial diet for 98 days before stocking.

Feeding behavior

Water clarity allowed observation of the feeding fish for the whole culture period. The average sample weight of the three trout strains is presented in Figure 8. The Hildebrand strain began feeding the first day food was offered; it was a week before the other strains were observed actively feeding. By 1 May, all strains were actively feeding. The Hildebrand and Growth strains rose higher in the cages when food was present than did the Kamloops. Feed pellets were added slowly which brought fish to the surface and then the fish sank to approximately mid-cage and continued feeding. As water temperatures increased, fish remained lower in the cage presumably selecting the cooler water. On the final three days the fish remained close to the cage bottom and little feeding was observed.

Water quality

Water quality measurements are recorded in Appendix Table 2.

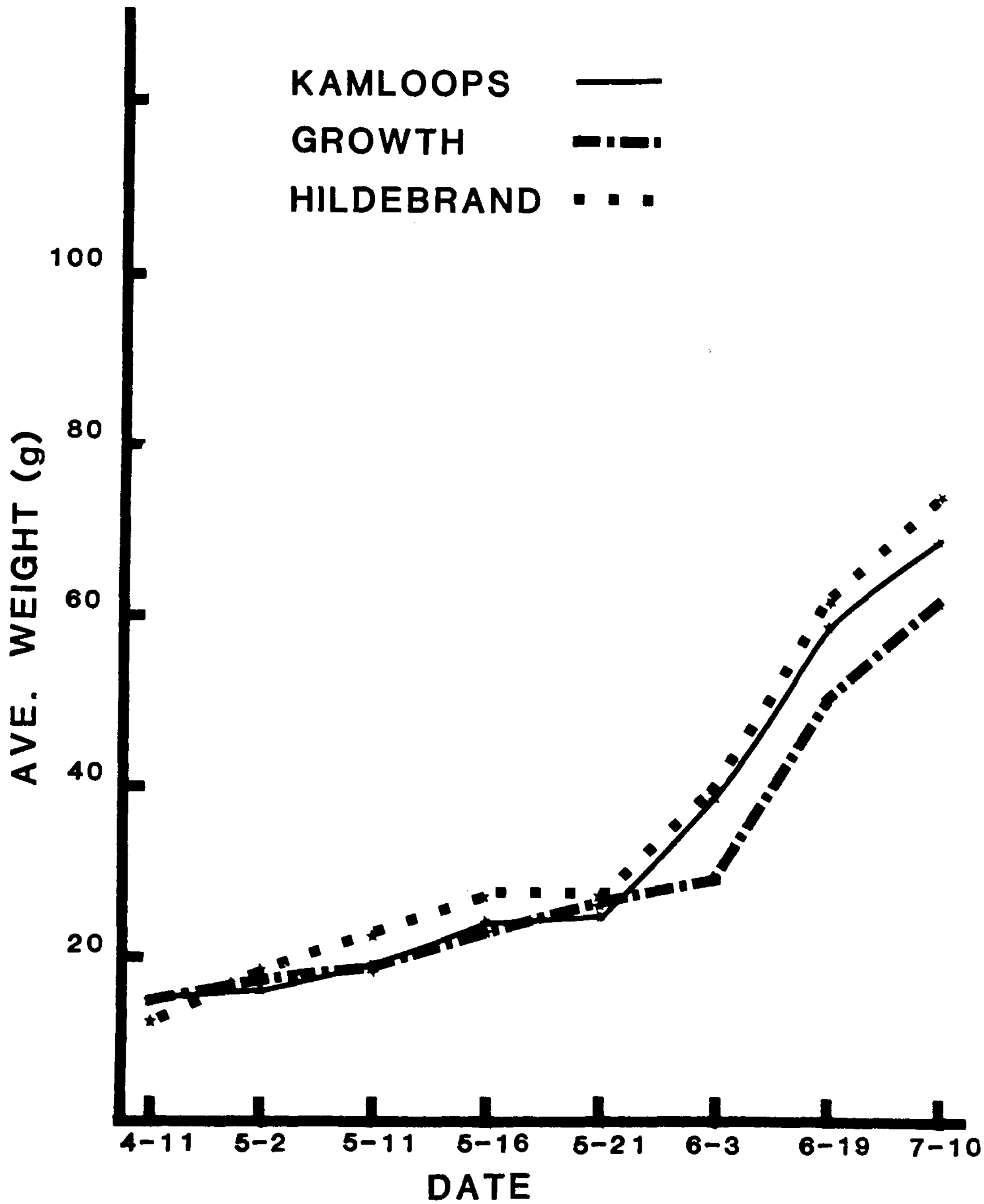

Figure 8. Growth of three strains of rainbow trout (Salmo gairdneri) cage cultured in eastern South Dakota. Weights from sampled fish taken between 11 April and 10 July, 1985.

Water temperatures were within rainbow trout preference range, 15-18 C, (Cherry et al. 1975), during the first 50 days of the culture period. June and July water temperatures reached 20.0 C or above which would increase metabolism (Smith 1982). Smith (1982) stated that mortality can be produced by a more or less constant "dose" of heat. Exposure to warm water for 40 days and then an increase of several degrees probably led to fish losses before harvest.

Dissolved oxygen was not limiting at any time during culture. Recorded measurements were all above 100% saturation. This was probably due to algal production and wind mixing which was common. Also the late afternoon time of sampling probably occured during the peak of dissolved oxygen production. A dissolved oxygen measurement taken at sunrise on 9 July was 9 mg/l at 2.5 m. No evidence of stressful dissolved oxygen concentrations were found during the study.

Strain performance conclusion

The Hildebrand strain exhibited larger increases in length, weight and condition than the other two strains. These differences illustrate the importance of investigating several strains of fish to identify the best one for a particular goal. Unfortunately the cage culture literature is remiss by not identifying the trout strains used. Of the strain evaluation studies published, most are management oriented for return to creel, which does not give comparable data.

Genetic differences exist between rainbow trout strains which have evolved from particular selection processes, either natural or man-induced. The performance of a particular strain will be affected by the environment to which it was exposed during growth. For cage culture in an elevated temperature regime, the Hildebrand strain performed significantly better ($p \leq 0.01$) than the two other trout strains examined.

1985 Feeding methods evaluation

Production

Production results of rainbow trout were measured upon complete harvest of all fish on 9 July, 1985 (Table 13). Significant ($p \leq 0.01$) differences were found by analysis of variance for the variables length and weight between the treatments (Tables 14 and 15). For both variables the hand fed fish were significantly smaller than the other treatments. No significant differences ($p > 0.05$) were found by analysis of variance for the variables Wr and food conversion (Tables 16 and 18). No significant differences ($p > 0.05$) exsisted in survival between treatments (Table 17).

Fish fed with the automatic feeder were slightly larger than the demand fed fish, 76.8 versus 73.8 g, respectively. Statler (1981) reported near double weight gain of demand fed fish versus hand fed fish. A problem in that study was that separate diets were fed to the demand fish and the hand fed fish, which may have contributed to the difference reported. No difference in weight or mean length was reported between hand fed and demand fed steelhead trout tested in production raceways (Kindschi 1984). Greater variaton in length was

Table 13. Growth, survival, and production results from cage culture of rainbow trout (*Salmo gairdneri*) testing three methods of feeding in an eastern South Dakota gravel pit between 11 April and 9 July, 1985.

	Demand	Hand	Automatic
Number of fish			
Initial	375	375	375
Final	316	291	308
Percent survival	84.3	77.6	82.1
Mean length (TL mm)			
Initial	107.3	107.3	107.3
Final	176.1	169.4	178.4
	(SD 21.8)	(SD 20.5)	(SD 18.6)
Mean weight (g)			
Initial	14.6	14.6	14.6
Final	73.8	64.2	76.8
	(SD 27.6)	(SD 21.8)	(SD 23.2)
Food conversion	3.5	3.4	3.0
Relative weight (Wr)	120.1	118.9	122.6
Mean individual weight gain/day (g)[a]	0.67	0.56	0.71
Mean biomass gain (kg/m^3)	2.38	1.76	2.42

[a]Based on number of days fed (88 out of 90 days held).

Table 14. Analysis of variance for dependent variable length from cage cultured rainbow trout (Salmo gairdneri) testing three methods of feeding in an eastern South Dakota gravel pit between 11 April and 9 July, 1985.

Source of Variation	Degrees of Freedom	Mean Square	F
Feeding Method (FM)	2	6,243.26	13.91**
Rep	4	1,031.68	2.29
FM X Rep	8	448.96	
Residual	900	412.33	

**Significant at the 0.01 level of probability.

Waller-Duncan *k*-ratio *t*-Test for the variable length.

Treatment (Feeding Method)	Mean (TL mm)	
Automatic Feeder	178.36	A
Demand Feeder	176.10	A
Hand Fed	169.41	B*

*Feeding methods with different letters are significantly different (*k*-ratio = 500).

Table 15. Analysis of variance for dependent variable weight from cage cultured rainbow trout (Salmo gairdneri) testing three methods of feeding in an eastern South Dakota gravel pit between 11 April and 9 July, 1985.

Source of Variation	Degrees of Freedom	Mean Square	F
Feeding Method (FM)	2	12,436.66	12.46 **
Rep	4	1,221.69	1.22
FM X Rep	8	997.91	
Residual	900	591.35	

**Significant at the 0.01 level of probability.

Waller-Duncan k-ratio t-Test for the variable weight.

Treatment (Feeding Method)	Mean (g)	
Automatic Feeder	76.76	A
Demand Feeder	73.80	A
Hand Fed	64.25	B*

*Feeding methods with different letters are significantly different (k-ratio = 500).

Table 16. Analysis of variance for dependent variable relative weight from cage cultured rainbow trout (Salmo gairdneri) testing three methods of feeding in an eastern South Dakota gravel pit between 11 April and 9 July, 1985.

Source of Variation	Degrees of Freedom	Mean Square	F
Feeding Method (FM)	2	1,189.71	1.95 NS*
Rep	4	254.97	0.42
FM X Rep	8	610.47	
Residual	900	122.95	

*Not significant at the 0.05 level of probability.

Table 17. Chi-square analysis for dependent variable survival from cage cultured rainbow trout (*Salmo gairdneri*) testing three methods of feeding in an eastern South Dakota gravel pit between 11 April and 9 July, 1985.

Feeding Method	Alive Observed	Dead Observed
Demand Feeder	316	59
Hand Fed	291	84
Automatic Feeder	308	67

χ^2 = 5.73 NS* with 2 df

*Not significant at the 0.05 level of probability.

Table 18. Analysis of variance for dependent variable food conversion from cage cultured rainbow trout (*Salmo gairdneri*) testing three methods of feeding in an eastern South Dakota gravel pit between 11 April and 9 July, 1985.

Source of Variation	Degrees of Freedom	Mean Square	F
Feeding Method	2	0.36	1.06 NS*
Rep	4	0.34	1.00
Residual	8	0.34	

*Not significant at the 0.05 level of probability.

recorded for demand fed steelhead (Kindschi 1984); larger length variation in demand fed fish was also recorded in this study. Frequent feeding with an automatic feeder appeared to increase size variability (Sawchyn 1984). Channel catfish (Ictalurus punctatus) had better weight gain when fed two or four times daily with an automatic feeder compared to just once daily (Greenland and Gill 1979).

The automatic fed fish had the highest mean Wr values,although not statistically different at ($p \leq 0.05$), followed by the demand and hand fed trout, respectively (Table 13). The general increase in Wr values agrees with observations that demand fed fish develop deeper bodies (Boydstun and Patterson 1982). Kindschi (1984) reported higher condition (K) for demand fed steelhead trout compared to hand fed steelhead. The automatic fed fish had the highest mean Wr values reported from nine cage culture studies in eastern South Dakota (Roell 1983; Schuler 1984).

Survival

No significant difference ($p>0.05$) was found in survival between the treatments (Table 17). Fish mortalities began in early June when water temperatures rose above 20.0 C (Appendix Table 2). During June and early July, 22 demand, 23 automatic, and 20 hand fed fish died. There was not a pattern except that these fish tended to be smaller than the sample average. On 7 and 8 July, 14 demand, 9 automatic, and 7 hand fed fish died. Final survival of these trout, which were all Growth strain, was overall better than that recorded for the Growth strain trout in the strain experiment. The fish in this experiment were harvested one day earlier than the strain experiment, which exposed the fish to a day less of high water temperatures. There was also the possiblity that localized low dissolved oxygen caused by decaying dead fish may have contributed to the lower survival in the strain experiment.

Feeding behavior

Feeding behavior of the hand fed fish was similar to that described in the strain experiment. The demand fed fish were conditioned to the dropping of food pellets when the trigger of the demand feeder was moved. A small amount of food was dumped from the feeder by hand during daily observation periods at the start of the experiment to condition the fish to feed. No fish were seen operating a feeder until 5 May, although the feeders had to be refilled before that time. It was common after that time to get a feeding response when the boat bumped the demand feeder cage thereby dumping a small amount of food pellets. Landless (1976) recorded peaks of feeding activity at dusk and through the night. Fish feeding activity was grouped, i.e., when one fish fed that activity created a response from other fish and feeding became rapid. Landless (1976) documented dominant fishes that worked the trigger of the demand feeder in his behavior studies. He stated that at higher densities several dominant fishes would likely be present. This was not observed in this study, but several fish were distinctly larger at harvest in each demand feeder cage.

The automatic feeders produced a larger fish than the other two treatments. The automatic feeders were programed to dispense 15 g of feed pellets at intervals between 0700 and 0900 hours and then between 1600 hours to dark. Ration was increased as the fish gained weight. A period of good growth was observed early in the experiment, then slowed until June when the growth rate again increased (Figure 9). Fish were not observed coming to the surface for feeding until 1 May. The normal feeding pattern was for the fish to increase their activity and rise to approximately the 1 m depth after the solenoid engaged. As temperature increased the fish remained closer to the bottom of the cage as did fish in all treatments.

Food conversion

Food conversion was not significantly different ($p>0.05$) between the feeding methods (Table 18). The automatic feeders had the highest efficiency at 3.0 (Table 13). The automatic feeder divided up the daily ration so that the fish were better able to injest the sinking pellets before any pellets sank out of the cage. An estimated 10 to 15 % of the feed pellets, estimate obtained by SCUBA, sank out of the cage before being eaten in the hand fed treatment. Andrews and Page (1975) stated that food conversion was not affected by frequency of feeding, but indicated that food intake and not utilization was the growth limiting factor in channel catfish studies. Catfish fed 24 times per day by automatic feeders had gained less weight than catfish fed at one, two, four, and eight times daily. This result may have been from greater physical or endocrine activity as a result of the hourly feedings (Andrews and Page 1975). The demand feeders were occasionally emptied by high wind and wave action which rocked the culture cages. This would result in wasted food.

Water quality

Water quality measurements were the same as collected for the strain experiment and are presented in Appendix Table 2. No major mortality occured due to temperature, although a steady low rate of mortality was recorded after temperatures exceeded 20.0 C.

Feeding methods conclusion

Feeding several times per day increased mean weights, lengths, condition, survival, and food conversion efficiency. An automatic feeder system was developed for remote location use. Demand feeders were also developed which were inexpensive to build and their use resulted in better growth than for hand fed fish. With the use of either a demand or automatic feeder, daily visits to the cage culture area could be reduced thus reducing labor costs.

Cage design

The cages used in these experiments were effective, but expensive and difficult to install and remove. Cage design was modeled after Roell (1983) who constructed the cages in the narrow design. A circular cage design would be cheaper to construct, using hoops and the plastic Vexar mesh (Williams et al. 1984).

Cage depth is important in areas where warm water temperatures could affect fish growth. Shallow depth of culture cages was partly responsible for low survival and poor growth in North Dakota (Hahn 1974). In fish cages 1 m deep used in 1985 to hold extra trout there was complete mortality before 1 July. The shallow depth of these cages did not allow fish to select cooler waters as a deeper cage would allow. Larger size cages can be effectively used on larger waters (Whitaker and Martin 1974; Oliver and Rider, in press). An individual land-owner would need few fish cages for production of a fish crop.

Economics of cage culture in eastern South Dakota

Cage culture of rainbow trout in eastern South Dakota is not economically feasable at this time. Due to a short culture period created by lethal water temperatures in June or July, rainbow trout strains used could not increase to a marketable weight of 200 g. Possibly the use of larger size rainbow trout fingerlings, 80 to 100 g, would produce a usable size fish; however the cost of the larger yearling rainbow trout would not be economical. I disagree with the economic assessment of cage culture in eastern South Dakota by Roell (1983) and Schuler (1984). Their ommision of labor costs, estimation of growth rate, and use of much larger fingerlings were not justified.

Cage culture conclusion

Rainbow trout were not reared to a desirable size in either a stock dam or a gravel pit. Small initial size of stocked fish and a culture period of 70 to 90 days which ended in late June or early July prevented growth to a 200 g size.

The maximum density of fish/m^3 was not discerned. Rainbow trout densities could still be increased to allow more production. Three m deep cages did permit trout to select cooler water temperatures.

Development and operation of an automatic feeder and a demand feeder allowed larger weight gains than did feeding by hand. The Hildebrand strain of rainbow trout performed better than two strains from the state of South Dakota in a gravel pit. Further strain evaluation investigation seems justifiable.

Cage culture of rainbow trout in eastern South Dakota should be discontinued unless a more heat tolerent strain of rainbow trout can be identified. Possibly future research into aquaculture for eastern South Dakota should focus on other fish species.

LITERATURE CITED

Anderson, R. O. 1980. Proportional stock density (PSD) and relative weight (Wr): interpretive indices for fish populations and communities. Pages 27-33 in S. Gloss and B. Shupp, editors. Practical fisheries management: more with less in the 1980's. Proceedings of the 1st Annual Workshop of the New York Chapter of the American Fisheries Society, Cazenovia, New York, USA.

Andrews, J. W. and J. W. Page. 1975. The effects of frequency of feeding on culture of catfish. Transactions of the American Fisheries Society 2:317-321.

APHA (American Public Health Association), American Water Works Association, and Water Pollution Control Federation. 1971. Standard methods for the examination of water and wastewater, 13th edition. American Public Health Association, Washington, District of Columbia, USA.

Ayles, G. B., J. C. I. Lark, J. Barica, and H. Kling. 1976. Seasonal mortality of rainbow trout (Salmo gairdneri) planted in small eutrophic lakes of central Canada. Journal of the Fisheries Research Board of Canada 33:647-655.

Boydstun, H., and T. Patterson. 1982. The pros and cons on the use of self-feeders. Salmonid 1:14-16.

Buck, D. H., R. J. Baur, and C. R. Rose. 1972. An experiment in the wintertime culture of trout in cages floated in a southern Illinois pond. Illinois Natural History Survey, Kimundy, Illinois, USA.

Cherry, D. S., K. L. Dickson, and J. Cairns, Jr. 1975. Temperatures selected and avoided by fish at various acclimation temperatures. Journal of the Fisheries Research Board of Canada 32:485-491.

Cherry, D. S., K. L. Dickson, J. Cairns, Jr., and J. R. Stauffer. 1977. Preferred, avoided, and lethal temperatures of fish during rising temperature conditions. Journal of the Fisheries Research Board of Canada 34:239-246.

Collins, R. A. 1972. Cage culture of trout in warmwater lakes. The American Fish Farmer 3:4-7.

Greenland, D. C., and R. L. Gill. 1979. Multiple daily feedings with automatic feeders improve growth and food conversion rates of channel catfish. The Progressive Fish-Culturist 41:151-153.

Hahn, D. R. 1974. The biological and economic aspects of cage rearing rainbow trout Salmo gairdneri, Richardson, in North Dakota. Doctoral dissertation. University of North Dakota, Grand Forks, North Dakota, USA.

Halverson, C. J., J. W. Jensen, and C. E. Boyd. 1980. Water quality in standing-water ponds for winter production of rainbow trout in Alabama. Transactions of the American Fisheries Society 109:310-313.

Kilambi, R. V., J. C. Adams, A. V. Brown, and W. A. Wickizer. 1977. Effects of stocking density and cage size on growth, feed conversion, and production of rainbow trout and channel catfish. The Progressive Fish-Culturist 39:62-66.

Kincaid, H. L. 1981. Trout strain registry. National Fisheries Center-Leetown. United States Fish and Wildlife Service. United State Government Printing Office:1981-355-158/9247, Washington, District of Columbia, USA.

Kincaid, H. L., W. R. Bridges, and B. von Limbach. 1977. Three generations of selection for growth rate in fall-spawning rainbow trout. Transactions of the American Fisheries Society 106:621-628.

Kindschi, G. A. 1984. Notes on two feed types and methods for steelhead trout production. The Progressive Fish-Culturist 46:44-47.

Landless, P. J. 1976. Demand-feeding behavior of rainbow trout. Aquaculture 7:11-25.

Lawler, G. H., L. A. Sunde, and J. Whitaker. 1974. Trout production in prairie ponds. Journal of the Fisheries Research Board of Canada 31:929-936.

Oliver, M., and L. Rider. 1986. Net pen aquaculture in Bull Shoals Reservoir. R. H. Stroud editor, Role of Fish Culture in Fisheries Management Symposium. American Fisheries Society Special Publication (in press).

Piper, R. G., I. B. McElwain, L. E. Orme, J. P. McCraren, L. G. Fowler, and J. R. Leonard. 1982. Fish hatchery management. United States Department of the Interior, Fish and Wildlife Service, Washington, District of Columbia, USA.

Roell, M. J. 1983. Rainbow trout (Salmo gairdneri) cage culture and primary production in eastern South Dakota dugout ponds. Masters thesis. South Dakota State University, Brookings, South Dakota, USA.

SAS (SAS Institute Incorporated). 1982a. A. A. Ray editor. SAS user's guide: Basics. Cary, North Carolina, USA.

SAS (SAS Institute Incorporated). 1982b. A. A. Ray editor. SAS user's guide: Statistics. Cary, North Carolina, USA.

Sawchyn, W. W. 1984. Intensive cage culture of rainbow trout in farm dugouts. Saskatchewan Research Council. Technical Report Number 161.

Schmittou, H. R. 1969. The culture of channel catfish, Ictalurus punctatus (Rafinesgue), in cages suspended in ponds. Proceedings of the Annual Conference of the Southeastern Association of Game and Fish Commissioners 23:226-244.

Schuler, G. D. 1984. Rainbow trout cage culture and benthic production in east-central South Dakota dugouts. Masters thesis. South Dakota State University, Brookings, South Dakota, USA.

Smith, L. S. 1982. Introduction to fish physiology. T. F. H. Publications, Inc., Neptune, New Jersey, USA.

Statler, D. P. 1982. Use of self-feeders for rearing steelhead trout at Dworshak National Fish Hatchery. The Progressive Fish-Culturist 44:195.

Steel, R. G. D., and J. H. Torrie. 1980. Principles and procedures of statistics. A biometrical approach. 2nd edition. McGraw-Hill Book Company, New York, New York, USA.

Tatum, W. M. 1973. Brackish water cage culture of rainbow trout (*Salmo gairdneri*), in south Alabama. Transactions of the American Fisheries Society 102:826-828.

Trzebiatowski, R., J. Filipiak, and R. Jakubowski. 1981. Effect of stock density on growth and survival of rainbow trout (*Salmo gairdneri* Rich.). Aquaculture 22:289-295.

Vodehnal, W. L. 1982. Rainbow trout production and water quality in eastern South Dakota dugouts. Masters thesis. South Dakota State Univeristy, Brookings, South Dakota, USA.

Wege, G. J., and R. O. Anderson. 1978. Relative weight (Wr): a new index of condition for largemouth bass. Pages 79-91 *in* G. D. Novinger and J. G. Dillard, editors. New approaches to the management of small impoundments. North Central Division of the American Fisheries Society Special Publication 5.

Westin, F. 1959. Soil survey, Brookings County, South Dakota. U.S. Government Printing Office, Washington, District of Columbia, USA.

Westin, F. C., and D. D. Malo. 1978. Soils of South Dakota. Agricultural Experiment Station Bulletin Number 656, South Dakota State University, Brookings, South Dakota, USA.

Whitaker, J., and J. Martin. 1974. The cage rearing of rainbow trout in precambrian lakes. Fisheries Research Board of Canada, Technical Report Number 446.

Williams, K., D. P. Schwartz, G. E. Gebhart, and O. E. Maughan. 1984. Small-scale caged fish culture in Oklahoma farm ponds. Langston University Agricultural Research. Langston University, Langston, Oklahoma, USA.

Appendix Table 1. Physical and chemical values of water quality recorded during cage culture of rainbow trout (Salmo gairdneri) in an eastern South Dakota stock dam between 18 April and 26 June, 1984.

Date	4-17	4-24	5-4	5-10	5-17	5-24	5-31	6-8	6-14	6-22	6-26
Temperature (C)											
Surface	10.9	10.5	10.0	13.5	18.0	17.6	17.9	19.8	19.2	24.0	27.0
0.5 m	10.9	10.5	10.0	13.0	18.0	17.6	17.6	19.5	19.2	23.2	26.5
1.0 m	10.5	10.5	9.5	12.8	17.8	17.5	17.5	19.4	19.0	23.0	25.0
1.5 m	10.0	10.5	9.5	12.5	17.5	17.2	17.2	19.1	19.0	20.0	24.0
2.0 m	9.1	10.0	9.0	10.8	17.5	17.0	17.0	18.9	18.9	19.2	23.0
2.5 m	9.0	10.0	8.5	10.4	17.5	17.0	16.9	18.6	17.0	18.6	21.5
3.0 m	8.8	10.0	8.5	10.0	17.2	17.0	16.9	18.0	16.4	18.2	21.0
3.5 m	8.5	10.0	8.0	9.5	17.2	16.8	16.5	17.2	16.0	18.0	20.5
Bottom	-	-	8.0	9.0	16.9	16.8	14.0	16.9	15.8	18.0	20.0
Dissolved Oxygen (mg/l)											
Surface	14.0	13.0	11.8	11.8	9.4	10.8	10.0	8.0	7.0	7.6	5.4
0.5 m	13.2	11.8	11.6	10.8	7.4	9.6	10.2	7.6	6.6	6.8	-
1.0 m	13.8	11.0	10.6	10.4	7.4	10.0	9.8	7.4	7.0	6.2	5.0
1.5 m	13.2	11.2	11.6	11.0	7.0	9.8	11.0	7.2	6.0	5.6	-
2.0 m	13.2	11.2	10.6	10.4	7.4	8.6	9.4	7.0	6.2	4.1	3.1
2.5 m	12.8	12.0	10.0	9.6	9.0	9.0	9.8	6.4	4.0	2.8	-
3.0 m	12.0	11.4	9.4	10.1	8.6	8.8	9.2	5.8	4.0	2.2	0.4
3.5 m	12.0	10.0	10.4	9.8	8.2	7.4	7.6	5.0	4.0	1.8	-
pH	8.4	8.6	8.4	8.4	8.3	8.5	8.6	8.4	8.1	8.3	-
Secchi disk (m)	0.75	0.85	1.30	1.50	1.20	0.85	0.85	0.30	0.40	0.30	-

Appendix Table 2. Physical and chemical values of water quality recorded during cage culture of rainbow trout (<u>Salmo gairdneri</u>) in an eastern South Dakota gravel pit between 11 April and 12 July, 1985.

Date	4-10	4-18	4-27	5-5	5-16	5-23	5-31	6-8	6-15	6-22	6-28
Temperature (C)											
Surface	13.5	16.0	13.0	16.2	16.0	19.0	19.6	23.0	21.5	22.0	21.0
0.5 m	-	15.5	13.0	16.2	16.0	19.0	19.6	23.0	21.5	21.8	21.0
1.0 m	10.5	14.5	13.0	16.2	15.6	19.0	19.6	23.0	21.0	21.2	21.0
1.5 m	-	13.2	12.0	16.0	15.4	18.4	19.6	21.0	20.5	21.2	20.5
2.0 m	10.0	12.5	11.5	16.0	15.4	18.0	19.0	20.2	20.5	21.2	20.4
2.5 m	-	11.5	11.0	15.5	15.0	18.0	19.0	19.6	20.0	21.0	20.2
3.0 m	9.5	11.0	11.0	15.2	14.6	18.0	19.0	19.2	19.8	20.4	20.0
4.0 m	9.5	10.5	11.0	13.5	14.4	17.0	18.6	18.8	19.5	20.0	20.0
5.0 m	9.0	10.0	11.0	12.0	14.0	16.0	17.0	17.5	17.5	18.8	18.5
Bottom	9.0	9.0	9.5	11.0	13.0	14.0	16.2	15.5	16.0	17.0	17.2
Dissolved Oxygen (mg/l)											
Surface	11.2	11.4	9.6	9.0	9.0	9.6	9.6	8.8	8.4	8.8	8.4
0.5 m	-	11.0	9.6	10.0	8.8	9.2	8.6	8.8	8.6	8.6	8.4
1.0 m	12.2	11.0	9.6	9.4	8.6	9.4	8.8	8.4	8.4	8.2	8.8
1.5 m	-	11.0	9.6	9.4	8.4	9.6	9.2	8.6	8.6	9.0	9.0
2.0 m	12.0	11.2	9.0	9.0	8.2	9.6	8.8	8.8	8.6	9.0	8.8
2.5 m	-	10.8	9.8	9.2	8.4	9.8	8.6	9.2	8.6	8.6	8.8
3.0 m	11.2	11.0	8.8	9.4	8.8	9.6	8.8	9.6	8.6	8.8	9.0
4.0 m	11.2	11.2	10.2	10.2	8.8	9.2	8.8	9.0	8.2	8.4	8.4
5.0 m	11.2	11.2	9.0	9.8	7.6	8.8	6.4	4.2	5.6	5.0	4.0
Bottom	10.8	9.0	6.8	5.8	6.8	5.4	2.6	3.4	7.6	3.0	2.0
pH	7.8	8.4	8.4	8.4	8.4	8.5	8.4	8.4	8.4	8.4	8.5
Secchi Disk (m)	1.80	1.70	1.60	3.10	1.50	2.80	1.70	2.90	2.30	2.20	2.10

Appendix Table 2. (continued).

Date	7-5	7-12
Temperature (C)		
Surface	24.0	25.5
0.5 m	24.0	25.2
1.0 m	24.0	25.0
1.5 m	23.5	24.2
2.0 m	23.2	24.2
2.5 m	23.0	24.0
3.0 m	23.0	24.0
4.0 m	22.2	24.8
5.0 m	20.0	21.0
Bottom	19.8	20.0
Dissolved Oxygen (mg/l)		
Surface	8.4	9.0
0.5 m	8.8	-
1.0 m	8.6	9.6
1.5 m	8.6	-
2.0 m	8.6	9.6
2.5 m	8.8	-
3.0 m	8.4	9.0
4.0 m	8.4	5.4
5.0 m	5.2	-
Bottom	5.2	1.8
pH	8.4	8.4
Secchi Disk (m)	3.40	1.80