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Rainbow Trout (Salmo Gairdneri) Cage Culture and Primary Production In Eastern South Dakota Dugout Ponds

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RAINBOW TROUT (*Salmo gairdneri*) CAGE CULTURE AND PRIMARY PRODUCTION IN EASTERN SOUTH DAKOTA DUGOUT PONDS

BY

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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.

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RAINBOW TROUT (Salmo gairdneri) CAGE CULTURE AND PRIMARY PRODUCTION IN EASTERN SOUTH DAKOTA DUGOUT PONDS

Abstract

MICHAEL JOHN ROELL

Rainbow trout (Salmo gairdneri) reared in 1 m^3 cages in a South Dakota dugout pond grew and survived as well or better than most cage-cultured rainbow trout reported in the literature. Significant differences ($P \leq 0.01$) in mean length, weight, and food conversion, and similarity in relative weight between trout fed 2 and 4% of body weight daily, indicated that the optimum feeding rate was near 3% for this size range (35 - 100 g). Daily rations based on fish size and water temperature need to be developed for trout reared in a lentic environment. The high cost of fingerlings was the limiting factor in a hypothetical dugout culture operation.

Greater water transparency seemed to be the major factor contributing to increased primary production, phytoplankton standing crop, and diel dissolved oxygen levels in comparisons between two unstocked dugout ponds. Suspension of sediments by wind action may have been greater in the older pond because it was 18% larger in surface area but only 66% as deep as the newer pond.

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INTRODUCTION

Salmonids in South Dakota are primarily restricted to the Black Hills, portions of the Missouri River mainstream reservoir system, and a few scattered ponds and streams of the state. Many residents do not have immediate access to these areas nor do they have the opportunity to purchase fresh trout. The majority of the lakes and streams east of the Black Hills will not support trout fisheries for more than a year due to winterkill and summerkill. Crops of rainbow trout (*Salmo gairdneri*) have been reared in the prairie pothole lakes of Canada and North Dakota (Miller and Thomas 1956; Johnson et al. 1970; Sunde et al. 1970; Lawler et al. 1974; Myers and Peterka 1976), but little has been done with trout in the lakes and ponds of eastern South Dakota and no work until recently has been done on dugout ponds.

Over 100,000 dugout ponds have been built in eastern South Dakota since the 1930s (Vodehnal 1982). These ponds could provide a medium in which landowners could rear crops of rainbow trout on an annual basis for food, sale, or recreation. Dugouts are primarily used for livestock watering but can also provide limited irrigation, fire control, wildlife use, and recreation (hunting and fishing). They have a high potential for winterkill and summerkill due to their shallow nature, small size, and nutrient loading from livestock and agriculture; therefore, annual fish crops appear to be the only feasible culture method. Not all dugouts would be suitable for rearing trout, but those with sufficient depth and water quality have potential.

Seguin (1970) demonstrated that trout could be successfully reared in floating cages if water conditions were compatible with the species. Subsequently, the cage rearing of rainbow trout has been oriented toward determination of optimum stock densities, stock sizes, and feeding rates and frequencies for various rearing conditions.

Advantages of the cage method over open-water culture include observation of feeding efficiency and fish health (Kilambi et al. 1977), manipulation of the harvest to fit market requirements (Schmittou 1969), cage mobility within the body of water (Seguin 1970), harvest of live fish (Whitaker and Martin 1974), not having to drain ponds for a complete harvest, culture of two or more species simultaneously (Jensen 1979), control of bad flesh flavor, control of environment, control of rearing density, reduced capital investment, flexibility in regulation of the operation size (Hahn 1974), complete harvest, uniformity of environment, use of bodies of water unsuitable for open-water culture, easier treatment of diseased fish, reduced predator losses, and reduced flood losses. Disadvantages include fin wear (Collins 1972; Boydstun and Hopelain 1977), inability of fish to seek a preferred location, vandalism (Tatum 1973; Newton et al. 1977), limited use of the natural food base, and cage costs.

Various limnological studies have been conducted in South Dakota dugout ponds. DiLauro (1982), Vodehnal (1982), and Schuler (personal communication) studied zooplankton productivity, water chemistry, and benthos productivity, respectively. Primary production, phytoplankton standing crop, and diel dissolved oxygen levels were monitored in this study to complement the above-mentioned work.

The objectives of this study were: (1) to determine if cage-reared rainbow trout could effectively grow and survive in a South Dakota dugout pond, (2) to make inferences on the economic feasibility of cage rearing rainbow trout on an annual basis, (3) to compare to unfed control fish the growth of rainbow trout fed 2 and 4% of body weight daily, (4) to speculate on the potential of rearing rainbow trout to a marketable size, and (5) to determine an annual cycle of primary production, phytoplankton standing crop, and diel dissolved oxygen levels in two unstocked ponds, one newer (2 years old)·and one older (5 years old).

STUDY AREA

Rainbow Trout Cage Culture

The pond site for cage culture was located approximately 6 km southeast of Brookings, South Dakota. The pond was chosen on the basis of the following criteria: representative of dugout ponds in eastern South Dakota, pond owner cooperation, high water level at the onset of the study, usable area of the pond (greater than 2.0 m deep to accommodate the cages), non-occurrence of other fish species, and a suitable distance from roads to prevent vandalism.

The pond selected had a surface area of 0.0624 ha (39.0 x 16.0 m) a usable area of 0.0191 ha (22.5 x 8.5 m), and a maximum depth of 2.8 m. Dead carp (*Cyprinus carpio*), black bullheads (*Ictalurus melas*), and frogs were found after ice-melt before the study, but no fish were caught when the pond was seined indicating a complete winterkill prior to the study. The pond bottom had a silt composition and was free of macrophytic plant growth. The long axis of the pond was oriented north-south with the soil from pond excavation located on the east and west sides. A small meandering creek, associated with a wetland, flowed past the pond approximately 25 m to the west. Water level was at a maximum in the pond at the onset of the study.

Primary Production, Phytoplankton Standing Crop, and Diel Dissolved Oxygen Levels

An annual cycle of primary production, phytoplankton standing crop, and diel dissolved oxygen levels was monitored within two unstocked dugout ponds located approximately 23 km east of Brookings, South Dakota. A relatively new pond excavated in 1980 and an older pond, dug in 1977, were chosen because they were located within 1.6 km of each other; the proximity of the ponds reduced the effects of differences in soil and weather, and minimized the time between measurements in each pond allowing for more valid comparisons. Both ponds had similar watersheds, moderate cattle use, and no aquatic macrophytes. The newer pond had a surface area of 0.0320 ha (21.3 x 15.0 m), a maximum depth of 2.9 m, and a mean depth of 2.0 m, while the older pond had a surface area of 0.0378 ha (26.6 x 14.2 m), a maximum depth of 1.9 m, and a mean depth of 1.3 m.

METHODS AND MATERIALS

Rainbow Trout Cage Culture

A randomized experimental design with three treatments (fish fed 0, 2, and 4% of body weight daily) of five replicates each was used. Three rows of five cages each were arranged parallel to the long axis of the dugout. The cages were anchored on their short sides with concrete blocks such that adjacent cages within a row had a common anchor. Cages were 2.0 m apart within and between rows.

The 1.0 x 0.5 x 2.0 m deep cages (Figure 1) were constructed of 12.7 mm mesh plastic netting secured to a frame of 38 mm^2 pine. Flotation consisted of two 0.305 x 0.305 x 0.610 m polystyrene blocks secured to the short sides of the cage. A 0.305 m deep feeding ring of 3.2 mm mesh plastic netting was attached to the inside of each cage to retain the floating feed. The removable lid had a 0.254 m^2 feeding port covered with 12.7 mm mesh plastic netting.

Rainbow trout fingerlings were obtained on 27 April 1982 from Cleghorn Springs State Fish Hatchery in Rapid City, South Dakota. The 34.5 g (146 mm) fish arrived in vigorous condition and were stocked directly into the cages at a density of 35 per m^3 (1.225 kg/m^3). Beginning 4 May 1982, a floating ration containing no less than 37.5% protein was fed to the fish once daily in the early evening. Wet weights of 10 fish were taken every two weeks from one representative cage of each feeding rate and amounts fed were adjusted accordingly. The trout were fed 47 of 58 days held and were harvested on 23 June 1982 when dissolved oxygen levels became critical. Each cage was pulled to

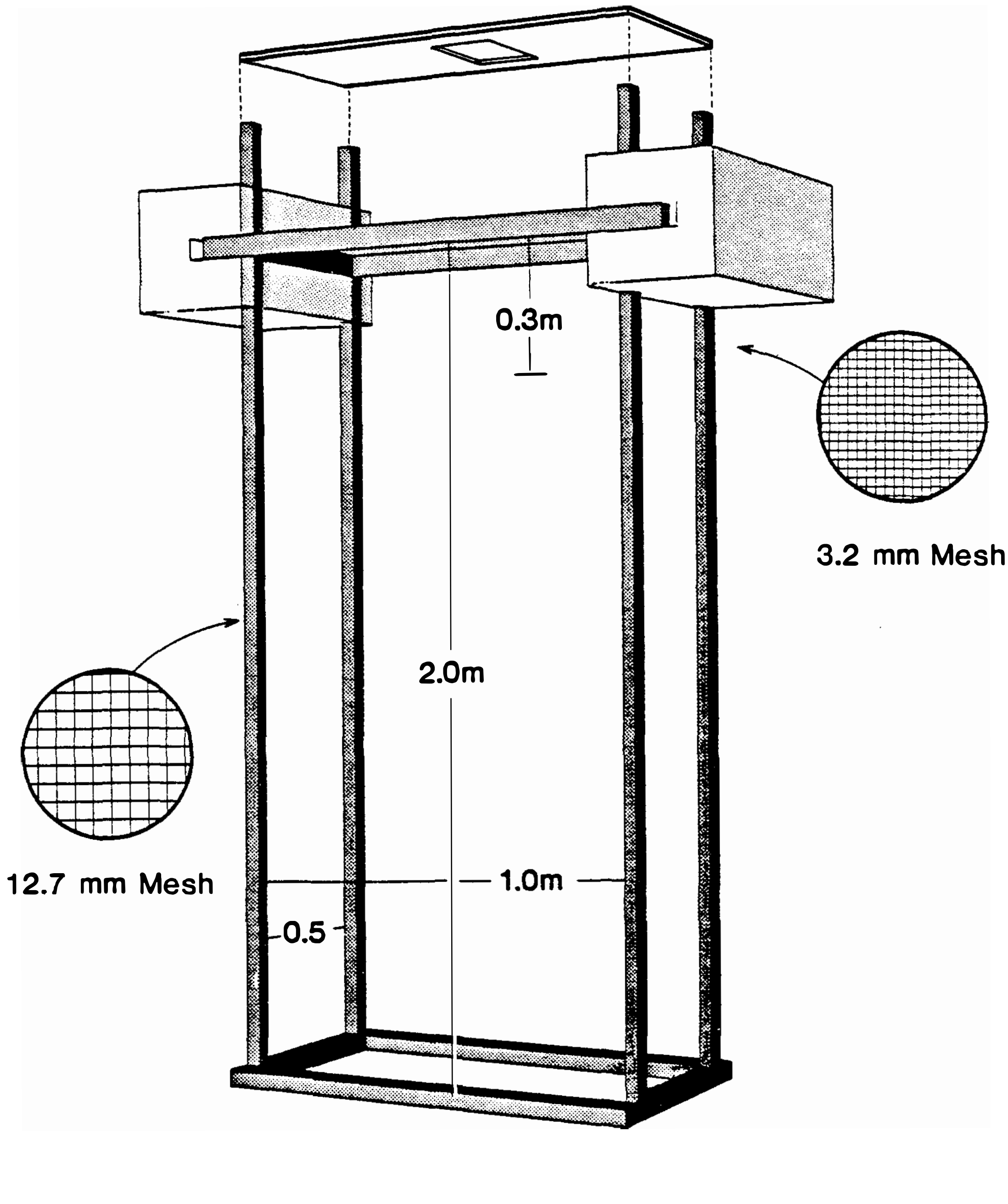

Figure 1. Cage design used in the culture of rainbow trout (*Salmo gairdneri*) in an eastern South Dakota dugout pond between 27 April and 23 June 1982.

the side of the pond and inverted to remove the trout. The fish were dressed and placed in ice-filled polystyrene coolers after measurement of total lengths (mm) and wet weights (g).

Relative weight (Wr), which compares actual weight (W) with a standard weight (Ws) for fish of the same length, was used as an index of condition. Wr values were calculated for each fish using the equation:

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

where

Wr = relative weight as an index of condition,

W = actual weight of the fish, and

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

Ws values were calculated from the following length-weight equation:

$$\log Ws = -5.194 + 3.098 \log L$$ (Weithman, personal communication in Anderson 1980)

where

L = total length of the fish.

The Statistical Analysis System (SAS) at South Dakota State University was used for data analysis. Analysis of variance was used to detect significant differences among treatments (feeding rates) for the dependent variables of length, weight, relative weight, and food conversion, while chi-square analysis was used for percent survival. The Waller-Duncan *k*-ratio *t* test was used to determine which treatment or treatments were significantly different for the dependent variables of length, weight, and relative weight. A ratio of *k* = 100, which loosely corresponds to a significance level of $\alpha = 0.05$ (Steele and Torrie 1980), was used.

Particular water quality characteristics were monitored biweekly at three stations, one near the center and one at each end of the cage arrangement. Temperature and dissolved oxygen were measured at surface, 1 m, 2 m, and bottom depths (these were monitored daily during the last week of the study). Temperature was measured with a Yellow Springs Instrument (YSI) Model 33 S-C-T meter, and the azide modification of the Winkler method (APHA et al. 1971) was used for dissolved oxygen measurement. In addition, water samples were collected at mid-depth, placed in 1.0 liter opaque Nalgene bottles, and kept in an ice-filled polystyrene cooler; from these samples, nitrogen-ammonia, nitrogen-nitrate, total and phenolphthalein alkalinity, and total hardness were determined in the laboratory using a Hach DR-EL/1 kit. Salinity and specific conductivity determinations were taken at mid-depth with a YSI Model S-C-T meter, and pH was measured at the surface with a Hach pH test kit. Secchi disk visibility and water depth were also measured at the three stations. All water samples were collected with a 2.2 l PVC Kemmerer sampler.

Primary Production, Phytoplankton Standing Crop, and Diel Dissolved Oxygen Levels

Primary production, phytoplankton standing crop, and diel dissolved oxygen levels were estimated concurrently in two unstocked dugouts, one newer (2 years old) and one older (5 years old), approximately every two weeks from July 1982 to July 1983. Determinations were made during relatively clear sky conditions, which helped avoid additional variation from date to date.

Primary Production

Various definitions of primary production terminology appear in the literature, therefore the following definitions (Eley 1970) were used in this study:

Gross Productivity (Pg) - The rate of energy stored as reduced organic material or the liberation of oxygen as a by-product of photosynthesis by photoautotrophic organisms.

Community Respiration (Rt) - The rate of oxidation of organic matter to provide energy for the life processes of the biota and the chemical oxygen demand of the abiotic components of the community.

Net Productivity (Pn) - The net rate of energy storage by the community or the difference between Pg and Rt.

Gross Productivity to Community Respiration Ratio (Pg/Rt) - The ratio of gross productivity to community respiration must be unity (Pg/Rt = 1.0) in a balanced steady state system, if no export or import occurs (Beyers 1963). If some event should disturb this ratio in such a manner that it becomes greater or less than unity, an increase or reduction of the biomass will take place.

The light- and dark-bottle (L and D) method described by Vollenweider (1969) and Lind (1979) was used to estimate primary productivity. Determinations were made at one central location in each pond at the surface and one-half meter depth intervals. Standard 300 ml BOD bottles were used. Pg, Rt, and Pn values for a given depth were calculated from oxygen concentration differences between a water sample exposed to light in a transparent (light) bottle and a sample not exposed in an opaque (dark) bottle. The initial oxygen concentration, which was theoretically the same in both the light and dark bottles, was determined in a similar size bottle. This was accomplished by filling all three bottles (light, dark, and initial) with water from the same Kemmerer sample, measuring the oxygen concentration in the initial bottle, and suspending the paired light and dark bottles at the depth from which the original water sample was taken. The bottles were clamped horizontally on a metal rack and suspended in the pond from sunrise to midday. They were then retrieved and the oxygen concentration of their contents was determined. All water samples were collected with a 2.2 l PVC Kemmerer sampler. The azide modification of the Winkler method was used for dissolved oxygen measurement; powder pillow reagents were found to be the most efficient means of oxygen determination in the field. Secchi disk visibility was measured after the bottles were retrieved and fixed with the reagents.

Rates of community respiration (Rt), net productivity (Pn), and gross productivity (Pg) were calculated for each depth from oxygen concentrations as follows:

Rt (mg O_2/liter/hour) = (I - D)/hours,

Pn (mg O_2/liter/hour) = (L - I)/hours, and

Pg (mg O_2/liter/hour) = Rt + Pn   (Lind 1979).

Final production and respiration values were converted to per square meter of pond surface as described by Haertel (1977) followed by conversion to milligrams of carbon by the equation:

$$\text{mg C/hour} = \text{mg } O_2 \text{ evolved/hour} \times 0.375/PQ \quad \text{(Strickland 1960)}.$$

A photosynthetic quotient (PQ) of 1.20 (Ryther 1956) was used. Pg and Rt values were converted to specific terms by dividing by mg chlorophyll *a*/m^2. Mg chlorophyll *a*/m^2 was calculated by averaging mg chlorophyll *a*/m^3 at all depths and multiplying by the mean depth of the pond. Specific values for Pn were calculated by subtracting specific Rt from specific Pg.

The light- and dark-bottle method was abandoned during ice cover for two reasons. First, holes had to be drilled quickly in pre-dawn "light" which caused upper-level water at the sample site to become mixed and aerated, thus preventing accurate determination of dissolved oxygen at these levels. Second, weather conditions at times prevented quick access to one or both ponds making the time interval between determinations at both ponds too great for valid results and comparisons.

Phytoplankton Standing Crop

Chlorophyll *a* concentration, as a measure of phytoplankton standing crop, was determined by the chlorophyll extraction method. Water samples for chlorophyll analysis were collected at surface and one-half meter depth intervals in the center of each pond with a 2.2 l PVC Kemmerer sampler and kept in 1.0 l opaque Nalgene bottles on ice until laboratory analysis. The spectrophotometric methods of Burnison (1980) were used for determination of chlorophyll *a* and, since the pheopigment degradation products of chlorophyll *a* are also detected, the following equation was used to calculate the concentration of pheopigment-corrected chlorophyll *a*:

$$\text{Chl. } \underline{a}\ (\text{mg/m}^3) = \frac{A \times K \times (664_o - 664_a) \times v}{Vf \times l} \qquad \text{(Lorenzen 1967)}$$

where

A = absorption coefficient of chlorophyll a,

K = 2.429, a factor to equate the reduction in absorbancy to initial chlorophyll concentration,

664_o = absorbance before acidification,

664_a = absorbance after acidification,

v = milliliters of acetone used for extraction,

Vf = liters of water filtered, and

l = pathlength of cuvette in centimeters.

The chlorophyll a extinction coefficient of Jeffrey and Humphrey (1975) was used to calculate the appropriate absorption coefficient. Absorbancies were measured with a Bausch and Lomb Spectronic 70.

Diel Dissolved Oxygen Levels

Diel fluctuations in dissolved oxygen concentrations at both ponds were monitored utilizing the community metabolism (diel curve) methods of Eckblad (1978) and Lind (1979). Dissolved oxygen concentrations were measured at one central location in each pond at surface and one-half meter depth intervals; these determinations were made on two consecutive evenings within one hour of sunset and on the interim morning within an hour of sunrise. The diel curves represent mean dissolved oxygen concentration from each of the three sampling periods. Water samples were collected with a 2.2 l PVC Kemmerer sampler, placed in standard 300 ml BOD bottles, and fixed with powder pillow reagents. The azide modification of the Winkler method was used for dissolved oxygen measurement. The community metabolism (diel curve) method was abandoned during ice cover for the same reasons previously described in the primary production methods.

RESULTS AND DISCUSSION

Rainbow Trout

Growth and Survival

Differences in mean lengths, weights, and relative weights (Table 1) among treatments were significant ($P \leq 0.01$; Tables 2 - 4). Analysis by the Waller-Duncan *k*-ratio *t* test revealed significant differences in mean lengths and weights among all three treatments; significant differences only occurred between mean relative weights of the unfed control fish and those fed (Table 5). Percent survival was significantly different ($P \leq 0.05$) among the treatments; however, since mortality was low, half of the expected values were less than 5.0 (Table 6) making the calculated chi-square value ($\chi^2 = 6.10$) biased. Also, the chi-square contingency table could not be collapsed to account for the bias, therefore the significance of the test should not be taken seriously.

Rainbow trout growth and survival were as good or better than most cage culture studies reported in the literature. Growth comparison with some studies was difficult since many were conducted during winter months (November to March) in southern states (Alabama and Arkansas).

In cage studies with high final rearing densities, stock density influenced individual growth of fish before it affected survival. Trzebiatowski et al. (1981) were the only authors reviewed who achieved higher percent daily weight gain (% DWG) than in this study. Even so, their % DWG values (6.58 - 8.55) diminished with increasing stock density (3.3 - 19.8 kg/m^3), but survival was not affected. This good growth was

Table 1. Growth, survival, and production results from the cage culture of rainbow trout (*Salmo gairdneri*) in an eastern South Dakota dugout pond between 27 April and 23 June 1982.

	Feeding Rate (Percent of Body Weight Daily)		
	0%	2%	4%
Number of fish			
Initial	175	176	175
Final	175	173	169
Percent survival	100.0	98.3	96.6
Mean length (mm)			
Initial[a]	146	146	146
Final	160	193	202
Mean weight (g)			
Initial[a]	34.5	34.5	34.5
Final	38.1	89.1	102.4
Mean relative weight (Wr)	88.2	113.4	113.4
Food conversion	-	0.979	1.837
Mean individual daily increment (g)[b]	0.077	1.162	1.445
Percent daily weight gain	0.22	3.37	4.19
Mean biomass gain per cage (kg/m^3)	0.126	1.877	2.253

[a] Based on a sample of 200 fish measured prior to stocking.

[b] Based on number of days fed (47 of 58 days held).

Table 2. Analysis of variance for dependent variable length of rainbow trout (*Salmo gairdneri*) cage-reared in an eastern South Dakota dugout pond between 27 April and 23 June 1982.

Source of Variation	Degrees of Freedom	Mean Square	F
Feeding rate	2	85787.43	652.17**
Between cages within treatments	12	131.54	1.09
Between fish within cages	502	120.67	

**Significant at 0.01 level of probability.

Table 3. Analysis of variance for dependent variable weight of rainbow trout (*Salmo gairdneri*) cage-reared in an eastern South Dakota dugout pond between 27 April and 23 June 1982.

Source of Variation	Degrees of Freedom	Mean Square	F
Feeding rate	2	198882.84	732.00**
Between cages within treatments	12	271.70	1.03
Between fish within cages	502	263.33	

**Significant at 0.01 level of probability.

Table 4. Analysis of variance for dependent variable relative weight of rainbow trout (*Salmo gairdneri*) cage-reared in an eastern South Dakota dugout pond between 27 April and 23 June 1982.

Source of Variation	Degrees of Freedom	Mean Square	F
Feeding rate	2	36880.65	504.34**
Between cages within treatments	12	73.13	1.33
Between fish within cages	502	54.99	

**Significant at 0.01 level of probability.

Table 5. Waller-Duncan *k*-ratio *t* test for the variables length, weight, and relative weight of rainbow trout (*Salmo gairdneri*) cage-reared in an eastern South Dakota dugout pond between 27 April and 23 June 1982.

	Feeding Rate		
	0%	2%	4%
Length (mm)	160	193	202
Weight (g)	38.1	89.1	102.4
Relative weight (Wr)	88.2	113.4	113.4*

*Underscored values denote no significant difference (*k*-ratio = 100).

Table 6. Chi-square contingency table for dependent variable percent survival of rainbow trout (*Salmo gairdneri*) cage-reared in an eastern South Dakota dugout pond between 27 April and 23 June 1982.

	Alive		Dead	
Feeding Rate	Observed	Expected	Observed	Expected
0%	175	172	0	3
2%	173	173	3	3
4%	169	172	6	2

due in part to the raceway-like rearing conditions at their cage location; good water flow and near-optimum rearing temperatures (weekly means ranging 10.1 - 17.3 C) of power station cooling water provided a quality growth environment for the trout.

Kilambi et al. (1977) found that growth of 149.5 g rainbow trout was significantly better at densities of 27.4 and 45.0 kg/m^3 than at 78.2 kg/m^3, but again survival was not affected. Collins (1972) reported that 57 g rainbow trout stocked at three densities in 1.54 m^3 cages had no significant differences in mean final weight; the stock densities were probably not near a maximum for the particular rearing conditions (warmwater lake).

Brauhn and Kincaid (1982) suggested that rainbow trout of different strains vary in their suitability for a particular use. If available, a strain selected for fast growth should be used in a cage culture operation.

Production

Mean biomass gain per cage for trout fed the low (2%) and high (4%) rates was 1.877 and 2.253 kg/m^3, respectively (Table 1). Stock densities (kg/m^3) were based on a per hectare rate from the literature (Halverson et al. 1980) for a similar size pond because it was thought the fish would have a significant impact on the biochemical oxygen demand. It was later apparent that many more fish could have been stocked and a much higher production realized.

Maximum final rearing densities (kg/m^3) have not been reported in the literature for cage-reared rainbow trout. Final rearing densities of 110 (Jensen 1979), 143 (Kilambi et al. 1977), and 170 kg/m^3 (Trzebiatowski et al. 1981) were reported but were not at a maximum. A maximum, corresponding to marketable-size (or landowner-usable) fish, may not manifest itself in reduced survival or reduced final production, but rather in reduced individual growth and poorer feed conversion rates. Trzebiatowski et al. (1981) reported a proportional increase in final production and food conversion with increasing stock density ($fish/m^3$), but found increases in individual weight to be inversely proportional to stock density. This may have been near the optimum stock density because the smallest fish (corresponding to the highest stock density) were still marketable (194 g). Wedemeyer (1976) suspected that high stock density hinders movement and feeding causing food availability, even at maximum or excess ration, to be a limiting factor. Ivlev (1961) reported a reduction in the amount of food consumed with increasing stock density in his work with fish other than trout; he suggested that there were probably behavioral effects on feeding due to stock density.

Water Quality

Physiocochemical values did not vary among the three monitoring stations within the cage arrangement, indicating that the trout had little affect on their immediate environment. Dissolved oxygen levels became critical before water temperatures did (Table 7), thus an immediate harvest of the trout was required on 23 June 1982. Percent saturation

Table 7. Mean physicochemical values of water quality characteristics monitored during the cage-rearing of rainbow trout (*Salmo gairdneri*) in a South Dakota dugout pond between 27 April and 23 June 1982.

	Date										
	4-30	5-16	6-2	6-14	6-17	6-18	6-19	6-20	6-21	6-22	6-23
Temperature (C)											
Surface	15.7	18.3	20.1	20.5	23.2	22.7	20.4	20.1	20.9	20.1	19.8
1 m	12.9	18.0	17.3	19.5	22.1	22.3	20.3	20.2	20.5	19.7	19.8
2 m	12.2	16.6	15.1	18.2	19.2	20.6	19.1	19.7	20.0	18.9	18.7
Bottom	10.9	15.6	14.3	15.2	15.0	15.2	15.3	15.3	15.4	15.6	15.6
Dissolved oxygen (mg/l)											
Surface	9.5	6.6	5.7	4.9	7.4	7.2	6.0	6.0	6.0	5.2	4.4
1 m	9.4	6.4	5.4	4.8	6.4	6.8	6.0	6.0	5.6	5.0	4.2
2 m	9.7	6.8	4.7	3.9	5.2	5.6	6.0	5.8	4.8	3.8	3.4
Bottom	8.2	6.1	2.8	2.1	2.6	3.0	3.2	3.6	1.6	1.2	0.8
Nitrogen-ammonia (mg/l)	0.59	1.07	1.28	1.26	-	-	-	-	-	-	-
Nitrogen-nitrate (mg/l)	2.5	0.7	0.5	0.5	-	-	-	-	-	-	-
Total alkalinity (mg/l $CaCO_3$)	130	187	202	205	-	-	-	-	-	-	-
Phenolphthalein alkalinity (mg/l $CaCO_3$)	0	0	0	0	-	-	-	-	-	-	-
Total hardness (mg/l $CaCO_3$)	277	325	315	308	-	-	-	-	-	-	-
Salinity (^{o}/oo)	0.2	0.2	0.3	0.4	-	-	-	-	-	-	-
Specific conductivity (μmhos/cm)	453	540	523	610	-	-	-	-	-	-	-
Secchi disk (m)	1.3	1.0	1.5	1.6	-	-	-	-	-	-	-
Depth (m)	2.6	2.7	2.7	2.7	-	-	-	-	-	-	-
pH	8.1	8.7	7.8	8.2	-	-	-	-	-	-	-

of dissolved oxygen ranged from approximately 35 - 50% in the water column at the time of harvest. Prolonged exposure to dissolved oxygen concentrations below 6 mg/l is generally considered stressful to rainbow trout. Cherry et al. (1975) found that attempts to acclimate rainbow trout to temperatures above 24 C caused mortality; a 7-day upper lethal temperature limit of 25 C was reported by Cherry et al. (1977) for rainbow trout.

Economic Considerations

Rainbow trout readily adapt to the cage environment (Collins 1972) and currently represent the optimum coldwater species for rearing to a marketable size. Even so, careful economic considerations must be made to receive a favorable return on investment in any culture operation. Most cage culturists would probably agree that the high cost of feed and fingerlings and the low return from the marketed product are the major economic limitations of rainbow trout culture. Necessarily, optimum stock density and size, feeding, cage design, and other factors must be determined for particular rearing conditions to reduce the impact of high rearing costs. Since the goal of cage culture is to economically achieve maximum growth, production, and survival given the conditions, the interaction of these factors must be optimized.

Although many of the cage culture studies reported in the literature were conducted in large natural lakes or impoundments, particular aspects of their results are applicable here; studies pertaining to cage culture in small farm ponds of the northern Great Plains were not found. The importance of stock density in relation to growth, survival, and production was discussed in the previous sections.

Stock Size. -- Initial size of stocked fish affects the final individual weight, and can be particularly important for a short rearing period as in this study. During the seven weeks trout were fed, the mean final weight of the higher fed fish (102 g) did not attain a landowner-usable size from a 35 g initial stock size (Table 1). Landowners and others who received harvested trout from this study liked the flavor but preferred a slightly larger fish; hence, a minimum size of 120 g was assumed to be landowner-usable.

In eastern South Dakota farm ponds the effective rearing period probably will not exceed ten weeks, hence a larger initial stock size may be required to attain a landowner-usable product. This, of course, will depend on availability of larger stock fish, and the additional cost of larger fish versus additional weight gained. Whitaker and Martin (1974) found that increasing the initial stock size of rainbow trout in cages from 1.7 to 7.8 and 13.9 g produced marketable fish (173 g round weight) in 122 days. They concluded that, while fish stocked at 12 g will produce a heavier fish at harvest, their higher cost is not economically justified. They recommended an initial size of 8 g.

Feeding. -- Food conversion (weight fed/weight gained; Table 1) of fish fed the high rate (4% of body weight daily) was nearly twice (1.837 vs. 0.979) that of those fed the low rate (2%) and was significant ($P \leq 0.01$; Table 8). Tadpoles, zooplankton, and other macroinvertebrates

Table 8. Analysis of variance for dependent variable food conversion of rainbow trout (*Salmo gairdneri*) cage-reared in an eastern South Dakota dugout pond between 27 April and 23 June 1982.

Source of Variation	Degrees of Freedom	Mean Square	F
Feeding rate	1	1.84	167.27**
Error	8	0.01	

**Significant at 0.01 level of probability.

were present throughout the study and may have contributed to the better food conversion of fish fed the low rate. The control fish gained no more than 4 g, so the effect of natural food on food conversion and growth may have been negligible. On the other hand, as the 2% fed fish became larger, they may have been able to utilize larger-sized natural food, thus improving food conversion values.

Floatability of the pelleted feed and differences in feeding behavior of the fed fish indicated that the optimum feeding rate was between 2 and 4%. Approximately one-fourth of the daily food ration immediately sank when presented. Fish receiving the low rate immediately fed on both sinking and floating pellets. Those receiving the high rate consumed only sinking pellets initially, but eventually fed on floating feed when there was no pond disturbance from the author; some pellets usually remained after feeding activity ceased, but probably provided less nourishment (when consumed later) due to leaching effects. Trout fed the low rate were apparently underfed making it unnecessary for them to compete for food to be satiated.

Mean relative weight similarities and food conversion differences (Table 1) of the fed fish also indicated that the maximum ration is between 2 and 4% for this size range of fish (35 - 100 g), and is probably near the 3% rate. Compared to the low feeding rate, the high rate apparently did not contribute to better condition (Wr) but did add significant weight and length. A similar study conducted by Schuler in South Dakota (personal communication) and a study in Alabama (Tatum 1973) revealed no significant differences in growth and survival between cage-reared rainbow trout fed 3 and 5% of body weight daily.

The actual feeding rates (percent of body weight daily) in this study were estimated by back-calculation from growth records and found to have means of 1.88 and 3.74% for the low and high rates, respectively, revealing the inaccuracy of predicting growth from periodic inventory of fish weights. Currently, there is no accepted methodology for feeding rainbow trout in a lentic environment. Cage culturists have utilized feeding charts from trout hatcheries (Whitaker and Martin 1974; Jensen 1979) or have inventoried fish weights at intervals and adjusted amounts fed accordingly (Tatum 1973; Hahn 1974; Kilambi et al. 1977; Trzebiatowski et al. 1981; and this study). Fish are either underfed resulting in lost growth or overfed contributing to higher feed costs. Papst et al. (1982) have developed a maximum growth rate model for rainbow trout fed at maximum ration (ration level at which maximum growth occurs). They used the approach of Stauffer (1973) who described a growth model for hatchery-reared salmonids using a dome-shaped growth-temperature curve. A dome-shaped curve best describes the relationship between temperature and specific growth in salmonids (Brett et al. 1969; Elliott 1975; Hokanson et al. 1977). The model of Papst et al. (1982) requires only temperature and initial fish size for estimating growth of cultured rainbow trout. Furthermore, the model can be calibrated for a specific culture system by estimating a constant from past growth records.

In general, fish reared in a lentic environment grow faster and have better food conversion values than similar-sized fish reared in a raceway at similar temperatures. Fish expend less energy in maintaining position in a lentic culture operation. Daily rations (as a percent of body weight) vary with fish size and rearing temperature. Ration tables similar to that used by Jensen (1979) need to be developed for rainbow trout reared in a lentic environment.

Cage Design. -- The optimum cage should be designed for the best economic return in relation to well-being of the fish. Design should be based on available material sizes to maximize return on the investment. The cages in this study were not designed to test economic feasibility of cage-rearing rainbow trout due to the small size of the pond and the number of replicates (cages) required for statistical analysis.

Water circulation at the intended cage location should be considered in cage design because high stocking densities could make dissolved oxygen limiting. Whitaker and Martin (1974) thought that lack of water circulation at a shore location was partly responsible for poor feeding and growth of cage-reared rainbow trout following outbreaks of bacterial gill disease. A gradient in dissolved oxygen concentration in their 14.5, 20.4, and 136.2 m^3 cages probably occurred, causing stressful conditions near the cage center, and likely contributed to the disease outbreaks. When the fish were transferred to cages at a location with good water circulation (mid-lake), feeding activity and growth rate improved for the remainder of the study. In bodies of water with poor water circulation such as dugout ponds, a rectangular cage design might prevent the problem. The more rectangular the cage, the higher is its surface-to-volume ratio, and thus the greater potential for effective water circulation. The additional material cost of this advantage should be compared to the intended benefit.

The costs of different materials and the intended lifetime of the cage should be considered. The higher expense of good rigid netting and framing material may lead to a better return on investment if the cage cost can be amortized over more years of use. The appropriate netting material should minimize wear on the fish and maximize effective water circulation.

Netting material is the greatest expense in cage construction, ranging approximately 48 to 77% of the total cage cost depending on the material. A cage constructed with 12.7 mm mesh nylon netting can be 43 to 56% less expensive than a similar cage constructed with 12.7 mm mesh plastic netting. There are advantages and disadvantages applicable to both. Although the nylon netting is less expensive, it may not withstand repeated handling and submersion in water as could plastic netting, and nylon netting is more prone to fouling from fish wastes, debris, and periphyton. Although more expensive, plastic netting is more durable and is readily cleaned; the greater expense may be justified if more years of use are realized.

The economics of a hypothetical dugout culture operation were developed for rainbow trout reared in a 7 m^3 (1.22 x 2.44 x 2.44 m deep) rectangular floating cage and fed 3% of body weight once daily for 50 days. Initial and final individual weights were assumed to be 35 and 100 g, respectively, such as in this study. The cost of fingerlings, estimated from a survey of private trout culturists, was $60 per hundred. In general, most culturists quoted prices of $0.10 per inch for fingerlings with no transport charge for capacity deliveries.

Cage stocking rates in this study were based on a per hectare rate reported by Halverson et al. (1980) for a similar size pond because it was assumed the fish would have a greater impact on the biochemical oxygen demand. It soon became apparent that more fish could have been stocked, hence a stocking rate of 5 kg/m^3 was assumed for this evaluation.

The estimated costs (Table 9) per kilogram of fish reared (round weight) reveal the relative impact of cage cost if it is all included in first year figures. Cage cost is relatively insignificant to the operation if it is amortized over just five years even though the cages would last longer with proper care. In this context, the use of the more expensive plastic netting is justified.

Water temperature in dugout ponds increases rapidly after ice-melt, but feeding in this study was not started until three weeks after this time. Hence, if feeding had started immediately following ice-melt, the fish could have conceivably reached a final individual weight of about 120 g based on growth records from this study. This would reduce the estimated rearing costs per kilogram by 14%.

A well-organized cooperative effort by landowners would minimize costs and enhance chances of success. Although the results of this study appear to be a step in the right direction, other questions need to be answered to fully assess the probability of a successful operation.

Primary Production, Phytoplankton Standing Crop, and Diel Dissolved Oxygen Levels

Specific values (mg carbon/mg chlorophyll *a*/hour) of gross and net production were more highly correlated to Secchi disk visibility than to chlorophyll *a* concentration (mg/m^3) in both ponds (Table 10).

Table 9. Estimated costs of a hypothetical cage-rearing operation for rainbow trout (*Salmo gairdneri*) in a 7 m^3 rectangular cage within an eastern South Dakota dugout pond.

Item	Cost
Fingerlings (35 g each)	
$60 per hundred Stock at 5 kg/m^3 = 1,000 fish	$600
Feed 87 kg @ $0.88/kg	77
Cage (plastic netting)	177
Total	$794
Total (less cage cost)	$677
Harvest	
1,000 fish at 100 g each Less 2% mortality = 980 fish Cost per kilogram	$ 8.10/kg (3.68/lb)
Cost (less cage cost) per kilogram	$ 6.91/kg (3.14 lb)

Table 10. Simple regression estimates for specific forms of production (mg carbon/mg chlorophyll _a_/hour) versus Secchi disk visibility (m) and chlorophyll _a_ concentration (mg/m^3) in two unstocked dugout ponds in eastern South Dakota during the ice-free season between July 1982 and July 1983.

Parameter	Regression Equation	R^2	R
Specific gross production			
1. New pond	Y = -0.46 + 11.26 log Sd	.73	.85
2. Old pond	Y = -2.46 + 4.59 log Sd	.57	.75
3. New pond	Y = 6.65 - 2.92 log Chl _a_	.48	-.69
4. Old pond	Y = 3.26 - 0.92 log Chl _a_	.15	-.39
Specific respiration			
1. New pond	Y = 0.44 + 1.79 log Sd	.13	.36
2. Old pond	Y = 1.24 + 1.20 log Sd	.17	.41
3. New pond	Y = 1.95 - 0.72 log Chl _a_	.21	-.46
4. Old pond	Y = 2.23 - 0.82 log Chl _a_	.52	-.72
Specific net production			
1. New pond	Y = -0.90 + 9.46 log Sd	.84	.92
2. Old pond	Y = 1.22 + 3.39 log Sd	.34	.58
3. New pond	Y = 4.70 - 2.20 log Chl _a_	.45	-.67
4. Old pond	Y = 1.04 - 0.11 log Chl _a_	.002	-.05

Specific values of community respiration were more highly correlated with chlorophyll *a* concentration in both ponds although all of the correlations were fairly poor ($R < |0.50|$) except for that of chlorophyll *a* concentration in the older pond ($R = -0.72$).

Haertel (1977) found that specific gross production was highly correlated with chlorophyll *a* concentration and density of algae in six eastern South Dakota prairie lakes; specific respiration and net production were also significantly correlated with algae standing crop. Livestock activity around the dugouts may explain the differences between this study and that of Haertel (1977). Turbidity increases from livestock probably contributed to additional light attenuation over and above that of phytoplankton. Secchi disk visibility therefore became a more important independent variable and was highly correlated with both specific gross and net production. Turbidity (in addition to algal standing crop) was probably not as influential in the open prairie lakes as it was in this study. Specific respiration in this study and that of Haertel (1977) was more highly correlated with chlorophyll *a* concentration than with Secchi disk visibility suggesting that respiration was more independent of light than of algae concentrations.

The Kurtz (newer) pond, in comparison to the Oppelt (older) pond, maintained higher dissolved oxygen concentrations (Figure 2), as well as higher gross production to community respiration ratios (Pg/Rt) and chlorophyll *a* concentrations (Figures 3 and 4) during the majority of the ice-free season. Water transparency differences between the two study ponds may explain these results, since the mean Secchi disk visibility of the Kurtz pond (1.8 m) was double that of the Oppelt

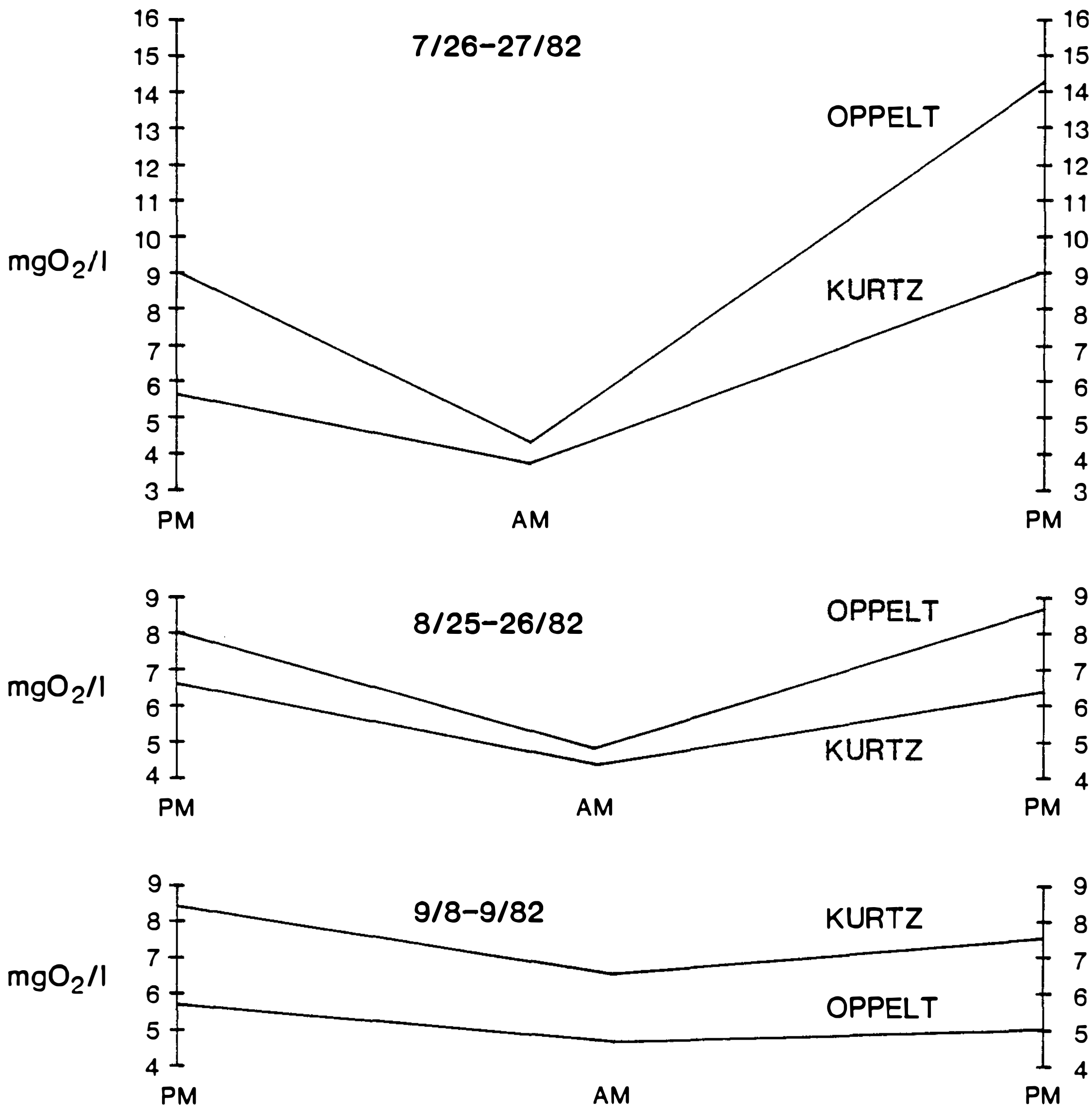

Figure 2. Diel dissolved oxygen curves by date in the Kurtz (newer) and Oppelt (older) ponds in eastern South Dakota during the ice-free season from July 1982 to July 1983.

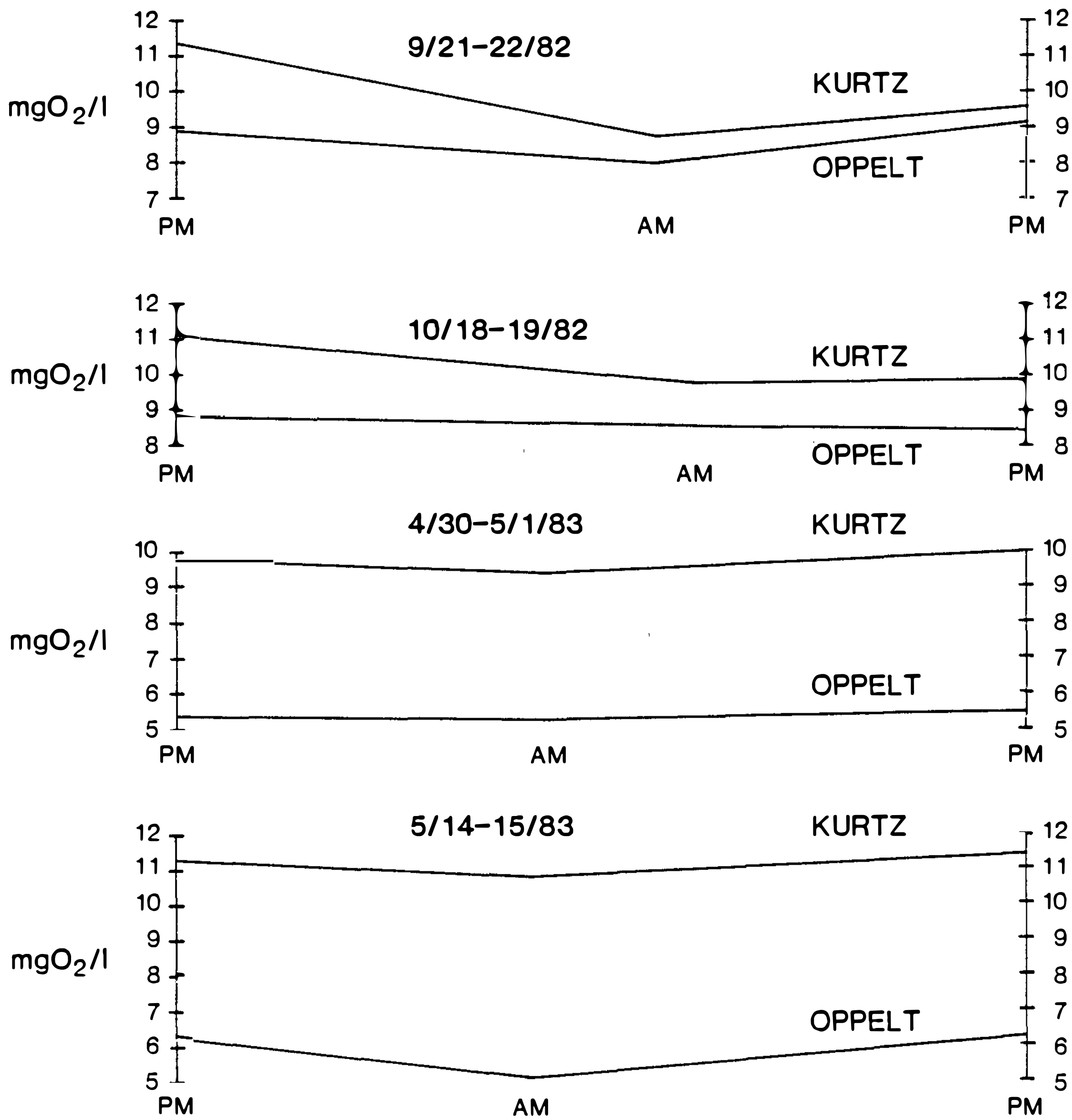

Figure 2. (Continued)

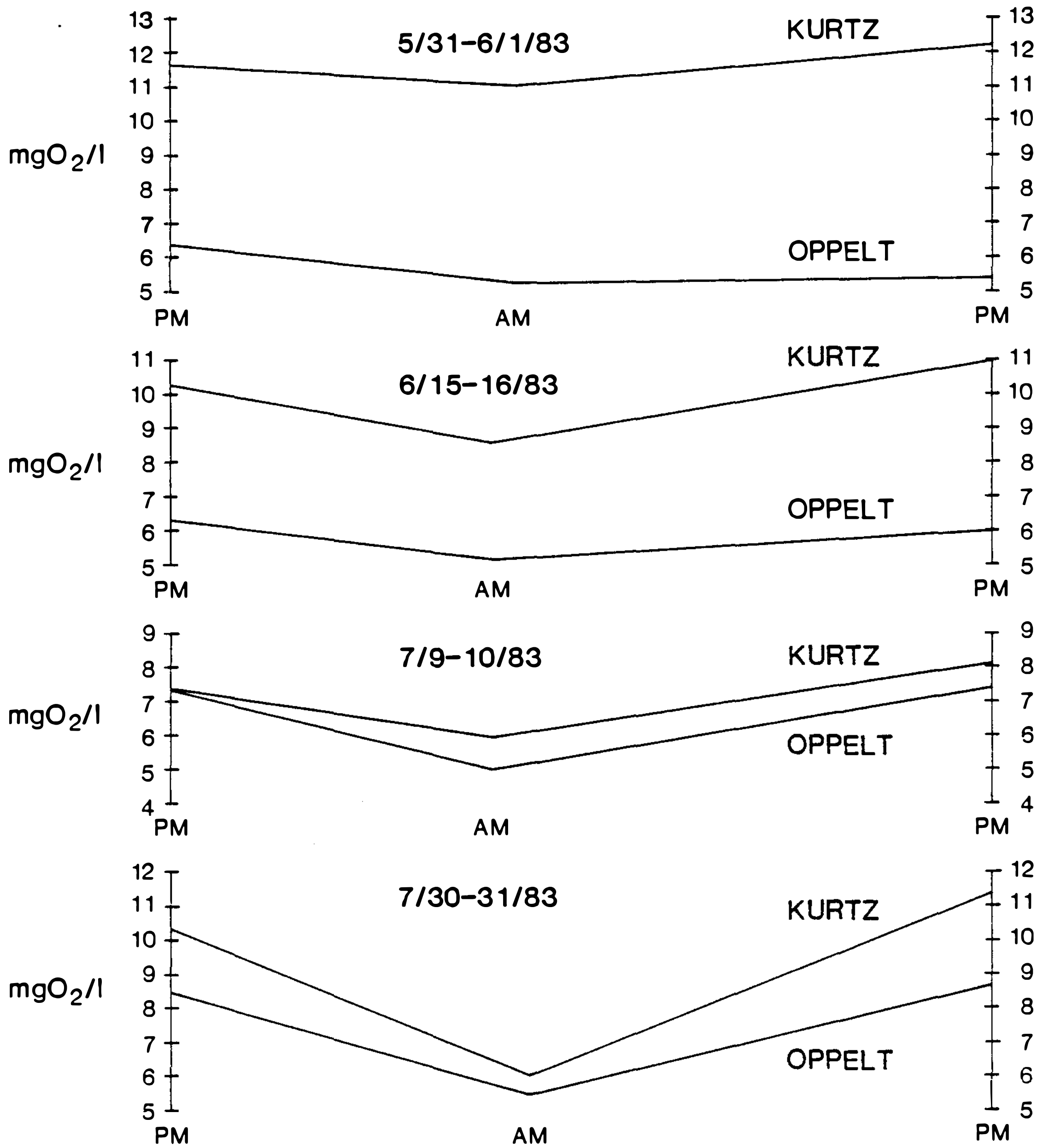

Figure 2. (Continued)

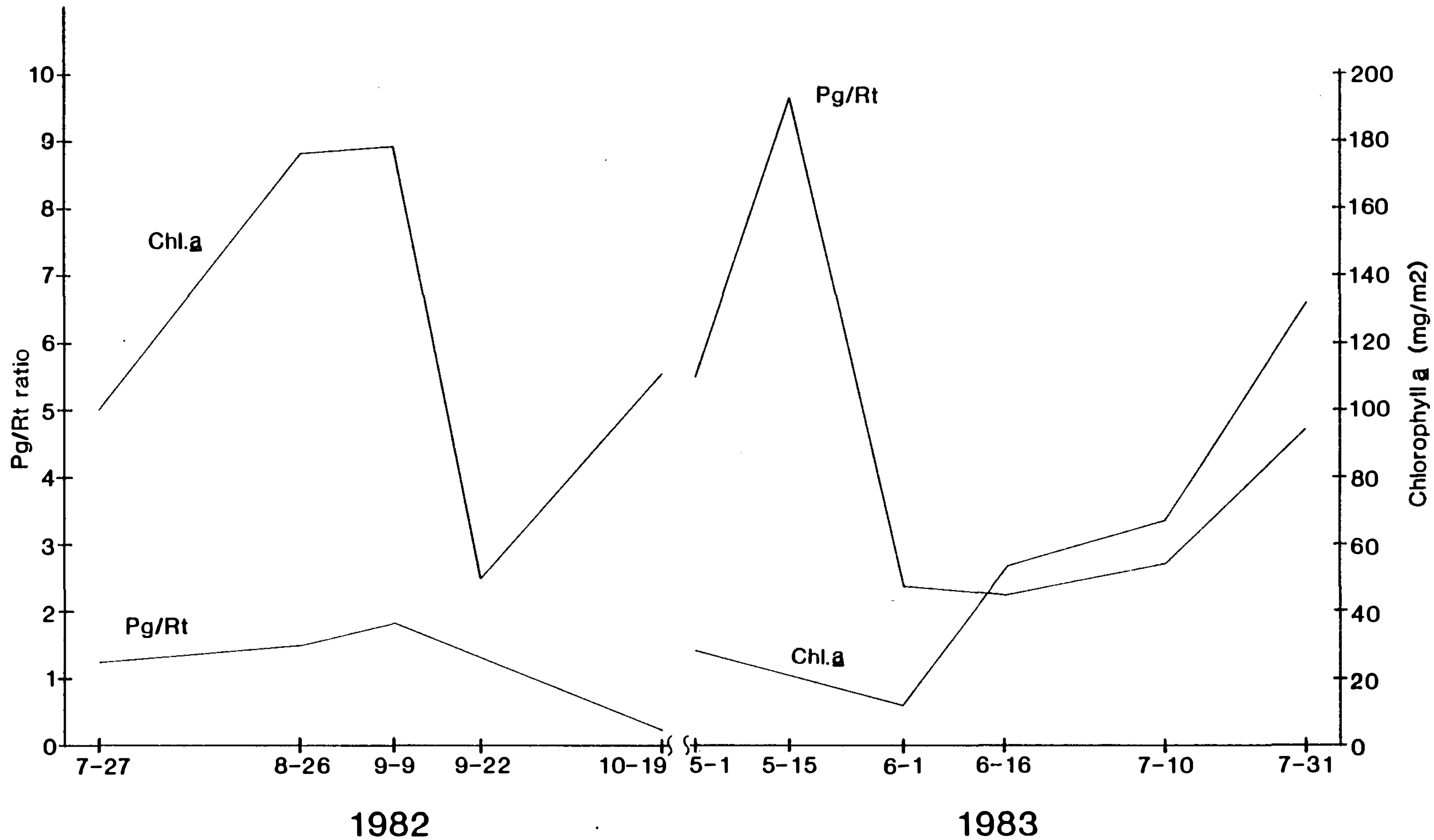

Figure 3. Gross production to community respiration ratios (Pg/Rt) and chlorophyll a concentrations (Chl. a) in the Kurtz (newer) pond in eastern South Dakota during the ice-free season from July 1982 to July 1983.

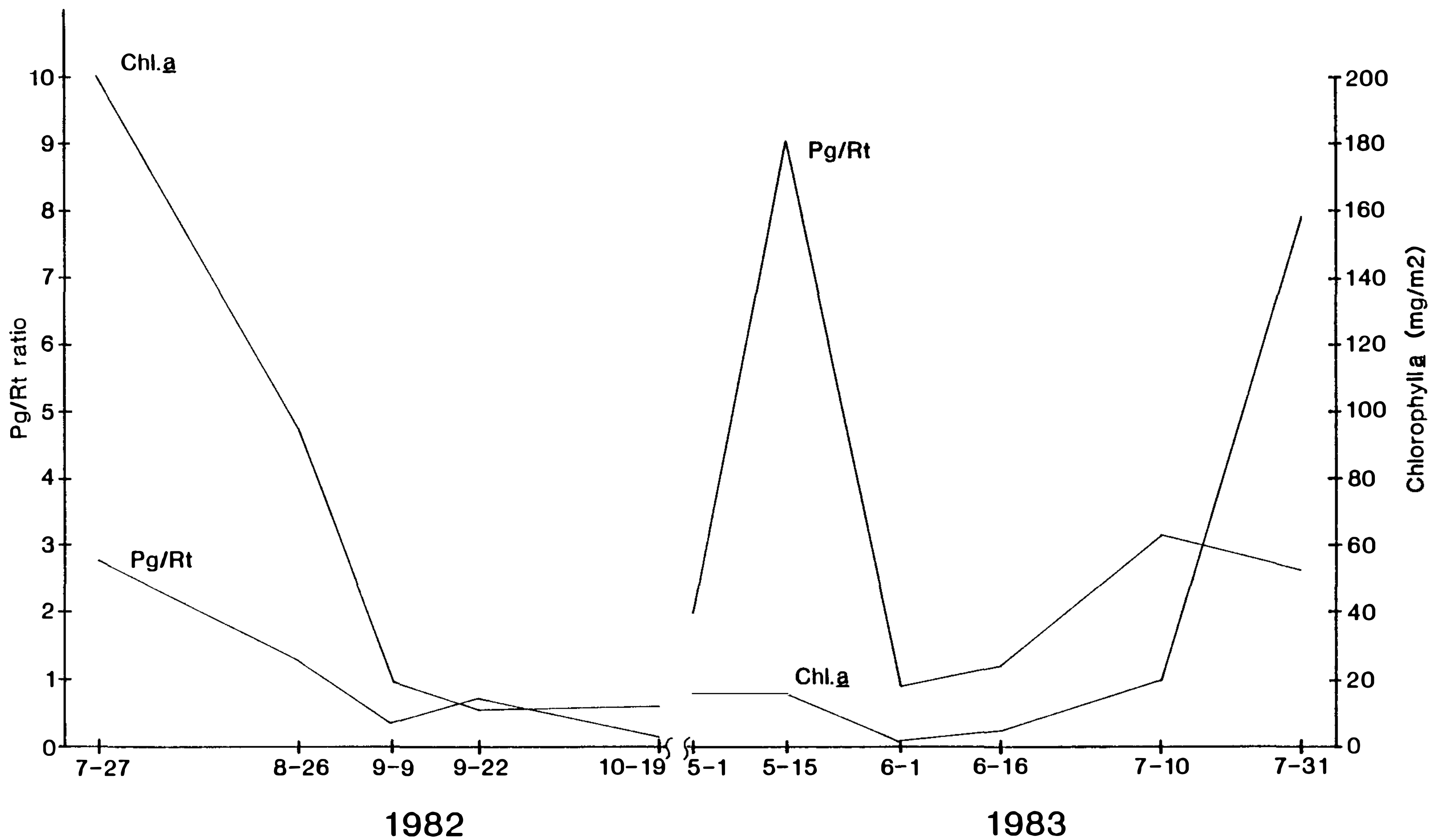

Figure 4. Gross production to community respiration ratios (Pg/Rt) and chlorophyll a concentrations (Chl. a) in the Oppelt (older) pond in eastern South Dakota during the ice-free season from July 1982 to July 1983.

pond (0.9 m). Hoyer and Jones (1983) suggested that if the phosphorus concentration of a lake is held constant, an increase in the concentration of inorganic suspended solids would cause the chlorophyll concentration to decrease. One hypothesis (Edzwald et al. 1976) is that phosphorus is adsorbed to inorganic suspended solids leaving less phosphorus available for biological processes. The Oppelt pond maintained higher total phosphorus concentrations than the Kurtz pond from July 1980 to July 1981 (Vodehnal 1982). If this was true during the course of this study, then inorganic suspended solids may have been the major factor contributing to differences in chlorophyll a concentrations between the two ponds.

Inorganic suspended solids also attenuate light and probably affect phytoplankton standing crop due to reduced photosynthesis. Hoyer and Jones (1983) found that the addition of inorganic suspended solids to their regression model of Secchi disk visibility versus chlorophyll a concentration accounted for 42% more variance ($R^2 = 0.84$) in water transparency.

Suspension of sediments by wind action may have been greater in the Oppelt pond since it was 18% larger (58 m^2) in surface area but only 66% as deep as the Kurtz pond. This may partially explain differences in turbidity between the two ponds. Livestock use seemed to be similar at both ponds (although it was not quantified), but also may have contributed to differences in turbidity between ponds.

Hutchinson (1967) and Odum (1971) described the early spring phytoplankton "blooms" characteristic of the lakes and ponds of the northern United States. In this study, mean chlorophyll a concentrations

(Table 11) indicated a phytoplankton bloom under the ice in both ponds prior to ice-melt. In addition, Pg/Rt ratios (Figures 3 and 4) and the specific forms of production and respiration (Table 12) revealed a bloom-type period following ice-melt during which accumulated nutrients were probably not limiting. Applegate et al. (1973) described the high algal concentrations of predominantly unicellular algae and the low species diversity occurring in late winter and early spring in a prairie lake of eastern South Dakota.

Ponds and lakes in South Dakota are very productive and dynamic, thus they are more difficult to study at one trophic level without considering effects from other trophic levels. Nonetheless, a limited study can provide important information which can be useful in formulating hypotheses about interrelationships among different components of the community.

Table 11. Mean chlorophyll a concentrations (mg/m^3; mg/m^2) by date from July 1982 to July 1983 for the Kurtz (newer) and Oppelt (older) ponds in eastern South Dakota.

Date	Kurtz mg/m^3	Kurtz mg/m^2	Oppelt mg/m^3	Oppelt mg/m^2
07/27/82	49.9	99.7	154.9	201.4
08/26/82	88.0	175.9	72.7	94.5
09/09/82	88.9	177.8	15.0	19.5
09/22/82	24.9	49.9	8.3	10.8
10/19/82	55.4	110.8	9.2	12.0
11/09/82[a]	30.0	60.0	20.8	27.0
12/02/82	17.3	34.6	13.9	18.0
12/17/82	15.0	30.0	12.1	15.8
01/02/83	19.6	39.2	6.9	9.0
01/13/83	20.8	41.6	6.9	9.0
01/29/83	34.6	69.3	8.7	11.3
02/10/83	177.8	355.5	12.1	15.8
02/28/83	39.2	78.5	3.5	4.5
03/14/83	16.2	32.3	26.0	33.8
03/28/83	19.6	39.2	76.2	99.0
04/19/83[b]	23.1	46.2	22.5	29.3
05/01/83	13.9	27.7	12.1	15.8
05/15/83	10.4	20.8	12.1	15.8
06/01/83	5.8	11.5	1.7	2.3
06/16/83	26.5	53.1	3.5	4.5
07/10/83	33.5	66.9	15.6	20.3
07/31/83	65.8	131.6	121.2	157.6

[a]First date with ice cover.

[b]Last date with ice cover.

Table 12. Specific forms (mg carbon/mg chlorophyll _a_/hour) of gross production (Pg), community respiration (Rt), and net production (Pn) in two unstocked dugout ponds in eastern South Dakota during the ice-free season between July 1982 and July 1983.

	Kurtz			Oppelt		
Date	Pg	Rt	Pn	Pg	Rt	Pn
07/27/82	0.978	0.796	0.182	1.041	0.375	0.666
08/26/82	0.707	0.473	0.234	1.236	1.020	0.216
09/09/82	0.810	0.447	0.363	0.240	0.437	-0.197
09/22/82	1.893	1.441	0.452	1.012	1.429	-0.417
10/19/82	0.076	0.311	-0.235	0.078	0.553	-0.475
05/01/83	3.102	0.564	2.538	1.726	0.851	0.875
05/15/83	3.189	0.331	2.858	5.355	0.593	4.762
06/01/83	4.657	1.949	2.708	2.917	3.250	-0.333
06/16/83	2.160	0.965	1.195	2.082	1.715	0.367
07/10/83	5.191	1.914	3.277	5.153	1.624	3.529
07/31/83	2.522	0.532	1.990	1.355	0.513	0.842

CONCLUSIONS

Rainbow trout growth was excellent, however, if landowners wish to harvest a larger-sized fish ($\geq$ 120 g), trout would have to be stocked at a larger size or some method would have to be developed to increase the growing season. Earlier stocking is a possibility as is deeper cages placed in deeper ponds. The latter possibility would need additional field study to determine its feasibility.

Trout survival was also excellent. This indicated that a landowner cage-culturing trout in a dugout could expect to harvest a large majority of the fish stocked if adequate care was taken to insure harvest before oxygen- or temperature-related mortalities occurred.

The study demonstrated that a landowner, with only a relatively small cage, could produce a large poundage of trout of usable size (though not as large as desired) in a short period of time. It also appeared that a greater stocking rate, maybe four times that of this study, could further increase production.

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